UNCLASSIFIED

AD NUMBER

AD872035

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; May 1970. Other requests shall be referred to Air Force Materials Laboratory, Wright-Patterson AFB, OH 45433.

AUTHORITY

AFML USAF ltr, 12 Jan 1972

THIS PAGE IS UNCLASSIFIED

AD872035

AFML-TR-70-4

(20)

FILAMENT WOUND FIBER GLASS WING TANK

D. ABILDSKOV
L. ASHTON
R. LYMAN
Fiber Science, Inc.

AD No. ———
DDC FILE COPY

TECHNICAL REPORT AFML-TR-70-4

MAY 1970

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (AFSC), Wright-Patterson Air Force Base, Ohio 45433.

AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

168

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report is made available for study with the understanding that proprietary interests in and relating thereto will not be impaired. In case of apparent conflict or any other questions between the government's rights and those of others, notify the Judge Advocate, Air Force Systems Command, Andrews Air Force Base, Washington, D.C. 20331.

This document is subject to special controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433. Distribution is controlled because of the technology discussed in the report.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

200 - June 1970 - CO455 - 122-2678

PAGES______

ARE

MISSING

IN

ORIGINAL

DOCUMENT

FILAMENT WOUND FIBER GLASS WING TANK

D. ABILDSKOV

L. ASHTON

R. LYMAN

Fiber Science, Inc.

FOREWORD

This report was prepared by Fiber Science, Inc., Gardena, California, under contract F33615-68-C-1622. The research was performed under Project Number 7381, "Materials Applications," Task 738101, "Exploratory Design and Prototype Development" and Special Projects Office (ASZSC-ASO). Inclusive dates of research were July 1968 through August 1969. The report was submitted October 31, 1969.

The Air Force Materials Laboratory Project Engineer is Mr. E. J. Morrisey (MAAE).

The authors wish to express their appreciation to Mr. J. Daines for his contribution in the area of structural analysis and to AFML Project Engineer, Mr. E. J. Morrisey, for his constructive criticism throughout this research study.

This technical report has been reviewed and is approved.

Albert Olevitch

ALBERT OLEVITCH, Chief
Materials Engineering Branch
Materials Support Division
Air Force Materials Laboratory

UNCLASSIFIED ABSTRACT

Ten (10) filament wound glass reinforced plastic, sandwich wall wing tanks were fabricated using a process amenable to low cost production. The tanks were 100-gallon capacity and designed to meet the Cessna A-37B wing tank geometry and loading excepting for internal pressure which was increased from 50 to 200 psig. The major problem experienced and solved during the program was the formation of a plastic liner. The liner also served as the winding mandrel which is the key to keeping the cost competitive with aluminum tanks. The feasibility of the filament wound tank was demonstrated with the successful fabrication of tanks that met all the structural and dimensional requirements. The process practicality was proven; however, the fabrication methods used during this program need to be further refined. Figure 1 shows the completed tank attached to the aircraft.

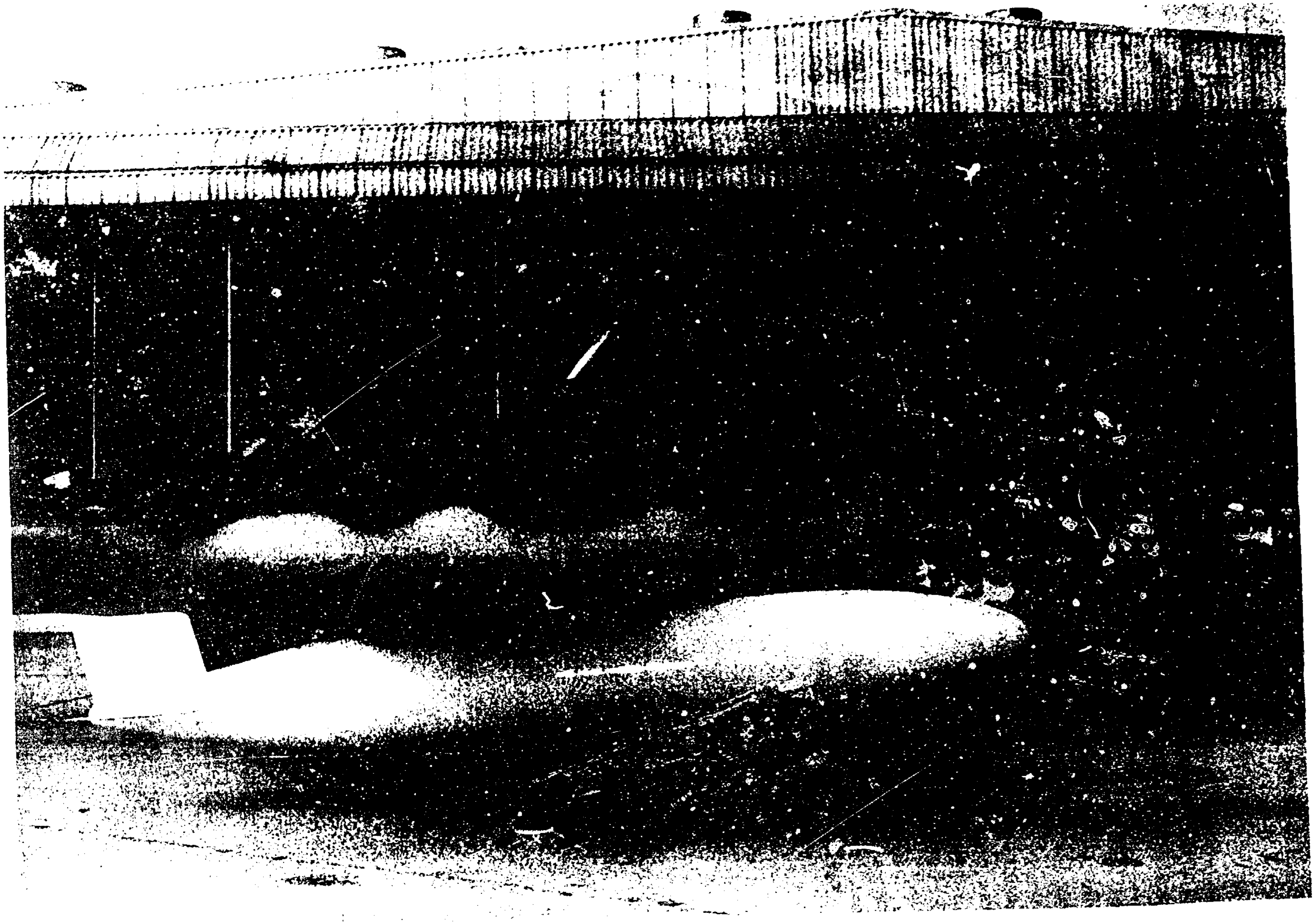


Figure 1. Completed Tank Attached to the Aircraft

CONTENTS

ILLUSTRATIONS

TABLES

SYMBOLS

A	Area (in.^{2})
A_g	Area per single end (204 filaments/end) = 20.76×10^{-6} in.^{2}
B.D.	Band density (ends/inch)
D	Dimension
E	Modulus of elasticity (psi)
EB	Base modulus of elasticity used in calculation of frame cross-section properties and base stresses
F	Allowable strength (psi)
f	Unit load (lbs/in)
G	Modulus of rigidity (psi)
H	Total height of frame and effective shell (in.), $\dfrac{2t_c t_f E_f}{3\sqrt{\lambda_f}(t_c + t_f)\bar{R}\,G_c}$
I	Moment of inertia (in.^{4})
K	Buckling coefficient
K_c	Axial compressive buckling coefficient for long sandwich wall cylindrical shells
K_t	Torsional buckling coefficient for long sandwich wall cylindrical shells
L	Length (in.)
M	Moment (in-lbs.)
M.S.	Margin of safety
P	Force (lbs.)
p	Pressure (psi)
Q	Shear (lbs.), moment of area (in.^{3})
q	Shear flow (lbs/in.)
R	Radius (in.)
S	Stress (psi)

S	$\dfrac{t_c t_f E_f}{2\lambda_f (t_c + 2t_f) E\, G_c}$
T	Thickness (in.)
T_y	Torsion (in-lbs)
t	Thickness (in.)
U	Shear stiffness
V_r	Resin volume fraction
W_r	Resin weight fraction
α	Helical winding angle (deg.)
β	Angle (deg)
δ	Length (in.)
γ	Angle (deg)
λ_f	$1 - \mu_f^2$
μ	Poisson's ratio
ρ	Density (lbs/in^3)
σ	Unit stress (psi)
τ	Unit shear stress (psi)
ψ	Coefficient of thermal expansion (in/in/^{o}F)

<u>SUBSCRIPTS</u>

b	Denotes bending
bru	Denotes bearing ultimate
c	Denotes composite or frame (See page 35)
cr	Denotes critical
cu	Denotes compression ultimate
e	Denotes min. or effective
f	Denotes sandwich faces

g	Denotes glass
i	Denotes inside
m	Denotes maximum
n	Refers to point n
o	Denotes outside
r	Denotes resin
s	Denotes shear or shell (See page 35)
si	Denotes interlaminar shear ultimate
su	Denotes shear ultimate
t	Denotes torsion
tu	Denotes tension ultimate
v	Denotes shear
x	Refers to the X axis
xx	Refers to the XX axis
yy	Refers to the YY axis
//	Denotes parallel to fiber orientation
$\perp$	Denotes normal to fiber orientation
α	Denotes helical direction
θ	Denotes hoop direction
1, 2, 3, 4, 5	Refers to a particular point or value

SUPERSCRIPTS

$-$	Denotes average
*	Denotes unit loading per inch

SECTION I

INTRODUCTION

The current metallic aircraft wing tanks have several deficiencies which can be eliminated with a filament wound, glass-reinforced plastic (GRP) tank; however, until recently, the manufacturing methods used for filament winding tanks were very costly. As a result, high quality filament wound tanks have been primarily used on missiles where the weight savings were very important and where competitive metallic tanks were also costly.

Recently FSI developed a new manufacturing process (patent pending) which greatly reduces the cost of filament winding tanks. The most significant feature of this new process is the elimination of a costly winding mandrel by thermoforming the tank liner (bladder) into the shape of the vessel, pressurizing it with air and using it as both the winding mandrel and the fuel-impermeable liner.

The purpose of this program was to demonstrate the feasibility of a glass-reinforced plastic tank which would be interchangeable with the existing aluminum wing tanks. Following is a list of potential advantages filament wound (GRP) wing tanks have over competitive aluminum tanks:

1) Higher strength-to-weight ratio.
2) Able to contain the pressure created by an internal fuel vapor explosion.
3) Elimination of internal foam as an explosion suppressant.
4) Tends to seal itself when hit by gunfire.
5) Absorbs the shock pressure of a high-velocity projectile into a liquid-filled tank.
6) Non-strategic material and corrosion-resistant.

SECTION II

SUMMARY

The tanks manufactured during this program all had the same basic configuration. They were designed to the Cessna A-37B flight loads and conformed to the external and attachment geometry of the existing aluminum tanks. The minor differences between tanks were made in an effort to solve either manufacturing or structural problems.

The tank consists of an acrylonitrile-butadiene-styrene (ABS) plastic liner, two glass-reinforced plastic internal frames, a sandwich-wall shell having filament wound skins and a polyvinyl chloride (PVC) foam core, two molded glass-reinforced epoxy polar caps, a sandwich-wall tail fin assembly having glass-reinforced plastic faces and a foam core, and a glass-reinforced plastic stiffened thermoplastic nose cap.

The major problems experienced during the program were:

1) Formation of a liner without wrinkles and without bridging across the corners of the internal frames.

2) The standard fill caps will not withstand 200 psig pressure and should be strengthened to be compatible with the glass-reinforced plastic tanks. The standard fill cap is designed for 50 psi pressure.

3) The forming of the foam required a special forming tool. The original plan was to form the foam by hand; however, the compound contours of the tank required a special forming tool.

4) Standard plumbing fittings need to be lengthened to allow for the thicker sandwich-wall construction.

5) The tank weight was higher than originally expected because of minimum winding thicknesses without leaving gaps between adjacent bands.

Problems which were anticipated that never materialized were:

1) Assembly of internal plumbing and fittings.

2) Tank roundness and dimensional control.

3) Penetrations through the shell for fittings and caps.

4) Unbonding of the internal frames from the shell because of internal pressure loading.

A total of ten tanks were wound; three were scrapped due to liner damage or failure experienced during the winding and curing operation; three were used for structural and qualification tests; one was painted and used for configuration check on aircraft (see Figure 1); and three were delivered to the Air Force. Details of the testing and disposition are summarized in Table I.

Table II gives a summary of the various tank sections and components along with their highest stress levels and corresponding margins of safety.

Significant among the results of this program are:

1) Wing tanks can be made by the filament winding process that are directly interchangeable with the currently used aluminum tanks.

2) The strength of the GRP tank is considerably higher than competitive aluminum tanks.

3) The weight of the GRP tank is less than competitive aluminum tanks. Optimum weight savings can be 40% less than foam-filled aluminum tankage.

4) Although the liner formation and method of support were the major problems experienced during the program, the concept feasibility was proven.

5) Tanks which will withstand the design loads, pressure, flight vibration, vapor explosion, and etc. can be fabricated on existing tooling with no further development required. Appendix I contains the tank drawings.

6) The estimated cost of a filament wound GRP 100-gallon tank in production is $819.00 (based on a production of 1,920 units @ 1969 price levels.)

The main text of this report is concerned with a review of the design, fabrication and testing of the tanks. The tank drawings and supporting data are presented in the appendixes and the supplement.

TABLE I

TANK DISPOSITION

S/N	TESTING	DISPOSITION
001	None	Used for checking mounting attachments and for display purposes. Held at FSI for disposition by WPAFB.
002	Structural	Failed at ultimate loading condition.
003	None	Tank lost during curing because of a compressor failure and loss of tank pressure.
004	Internal Pressure	Cap "O" ring blew at 80 psig. Retested to 125 psig. Failed through line of tank fittings.
005	Internal Pressure	Pressure held at 175 psig for 20 minutes. Liner leaked causing the foam to separate from the GRP faces.
006	Internal Pressure	Pressurized to 50 psig. Tank shipped to Wright-Patterson Air Force Base for slosh and vibration testing.
007	Internal Pressure	Pressurized to 50 psig. Tank shipped to Wright-Patterson Air Force Base for slosh and vibration testing.
008	None	Tank lost during cure. Internal winding hardware wore a hole through the liner causing it to leak.
009	None	Tank lost during winding. Liner did not conform to frames and ruptured at 20 psi internal pressure since it was not supported by the wound glass.
010	External Pressure Internal Pressure Structural Tail Fin	Tank subjected to ultimate loads except for normal load on vertical tail fin which was only subjected to 82.5% of ultimate load. Held at FSI for disposition by WPAFB.

TABLE II

STRESS SUMMARY

COMPONENT	TYPE STRESS	STRESS PSI	MARGIN OF SAFETY
Tank - Hoop Fibers - External Pressure	Tensile Buckling	76,000 17.2*	0.70 2.82
Tank - Inertia Loads	Bending Shear Buckling-Bending Buckling-Shear	8,500 2,940 11,000 15,200	High High (Positive Combined)
Polar Ring - Flange - Bolts	Bending Tensile	13,700 28,100	.82 4.70
Covers - Internal Pressure - External Pressure - Shear Lip	Tensile Buckling Shear	10,000 96* 1,500	1.50 20.30 7.00
Fins - Face Wrinkling - Core - Skins, Bending	Compression Shear Tensile	13,500 24 13,500	.16 4.20 2.26
Tail Cone	Bending Shear	7,120 107	5.17 .17
Fin to Tail Cone Foam	Bending Shear	2,410 24.2	0 High
Frame - Outside Tank Skin - Inside Tank Skin - Side Skins (181) - Inside Frame Skin - Side Skin (181) - Shell Core - Frame Core	Compression Compression Tension Tension Shear Shear Shear	20,813 8,877 15,646 23,157 12,652 330 52	High High 2.19 High .03 .24 ** 1.40
Frame Attach Fitting - - Nut Shear Out - Beam Bending - Column - Bond	 Shear Tension Compression Shear	 2,890 13,240 21,900 2,628	 3.02 .89 .69 .14

* Pressure, psi
** Assume Shear Strength = 400 psi

SECTION III

DESIGN CRITERIA

The criteria used in the design of the wing tank were as follows:

The tank should be interchangeable with aluminum tanks currently used on the Cessna A-37B airplane.

The fabrication method should be amenable to low cost, high production rates.

Useable fuel capacity = 100 gallons.

Suspension parts MIL-A-8591.

Target weight = 50 pounds.

Minimum margin of safety* = 0.5.

Design loads.

Normal operating pressure = -3 to 4 psig.

Ultimate pressure = 150 psig.

Burst pressure = 200 psig.

Inertia and air loads - Reference 1 and page 40.

Slosh vibration and vibration MIL-T-7378.

* Except for internal pressure.

SECTION IV

TANK DESIGN AND ANALYSIS

1. DESIGN DISCUSSION

The wing tank was designed in accordance with the envelope and loading requirements imposed on the Cessna A-37B aluminum wing tanks except the internal pressure capability was increased from 50 to 200 psig.

Appendix I contains the tank drawings. Basically the tank is a sandwich-wall shell having GRP filament wound faces with a 4 lb/ft^3 polyvinyl chloride foam core wound over an ABS thermoplastic liner. Inside the tank are two frames which redistribute localized tank attachment loads to the tank shell. The frames are each 3 inches wide and vary in depth from .088 inches at the tank bottom centerline to 3.088 inches at the top centerline. To prevent the sides of the frame from being overstressed by the internal tank pressure, they are filled with a 6 lb/ft^3 foam. Bonded inside the frame at the tank's top centerline is a molded GRP molar which serves to feed the lug load in to the frame flanges. These molars (one for each frame) also help to support sway brace pads. The sway brace pads are solid GRP laminates that replace the foam core in the basic tank shell opposite the sway braces. The polar openings (required for winding) are each reinforced by a molded GRP polar ring to which is bolted a GRP molded cap.

The nose of the tank has a thermoformed fairing cap which is reinforced by GRP laminate that also bolts to a high density foam ring. The foam ring bonds to the outside surface of the shell. This cap serves only as a fairing and therefore does not feel the internal tank pressure.

The tail section (fins) is a sandwich-wall construction having GRP-laminated faces and a 4 lb/ft^3 foam core. The foam core in the juncture region (fins to cone) is high density (31.2 lbs/ft^3) since this region is subjected to higher stresses because of the changes in loading directions. The entire tail section bolts directly to a high density foam ring. The foam ring bonds to the outside surface of the shell. The tail section does not feel the internal tank pressure.

The sandwich-wall construction of the basic shell is required for stability considerations (beam bending compressive loads and external pressure) and will minimize sloshing and vibration problems by increasing the hoop stiffness, thus raising the natural frequency of vibration.

Table III presents the materials selected for use for the various tank structure and components.

TABLE III

TANK MATERIALS SUMMARY

APPLICATION	MATERIAL	MANUFACTURER	SPECIFICATION
Internal Tank Liner	ABS Tubing	Marbon - Borg Warner	E-1000
Polar End Fittings	Compression Molded 1/2" Glass Fiber Epoxy Material	U.S. Polymeric	E-7102
End Closures	Compression Molded 1/2" Glass Fiber Epoxy Material	Fiberite Corporation	E-7111
Nose Fairing	ABS Sheet-Vacuum Formed	Marbon - Borg Warner	Type E or T
Tail Cone and Fins	Lamination 181 Glass Cloth and Epoxy Resin System with 4#/ft^3 Polyurethane Foam Core	Selected Suppliers (See Appendix III)	
Support Frames	Lamination 181 Glass Cloth and Epoxy Resin System with 6#/ft^3 Polyurethane Foam Core	Selected Suppliers (See Appendix III)	
Support Molar	Compression Molded 1/2" Glass Fiber Epoxy Material	U.S. Polymeric	E-7102
Winding Resin	Blended Epoxy Resins for Fire Retardance	Dow, CIBA, U.S. Royal, Harshaw, Union Carbide, Rohm & Haas	See Appendix III
Filament Glass	Single-End Roving Alternate 9-End Rovings	Glass Fiber Products Ferro Corporation	AeroRove 3 S-1014

2. MATERIAL APPLICATION

a. Liner. It was not the intent of this program to develop a new inside tank liner, thus the choice of material was determined from previous forming experience, ductility, formability, and bonding with epoxies. Several candidate materials were considered--primarily ABS, PVC, Nylon, Polyethelyne, Polypropylene, and Polycarbonate. PVC was rejected because of the difficulty experienced in blow forming in an earlier application and because of the difficulty in bonding to PVC materials. Polycarbonate was rejected due to the material cost and the difficulty in setting up the moisture control prior to forming. The olefins were rejected because of bonding problems and the lack of solvent welding capability. Nylon was not used anticipating forming difficulties.

ABS Grade E was chosen over other Marbon grades due to the characteristics of low modulus, soft pliable nature, high extensibility, ease in achieving excellent forming, and the highest chemical corrosion resistance. Samples of ABS which have been soaking in JP-4 fuel for 2 1/2 years have shown no effects except a slight swelling after approximately one year. There were no attempts to eliminate the elastic memory of the formed liners.

Other materials and/or blends of thermoplastics could be chosen which may equal or exceed the advantages of Marbon ABS Grade E; however, it was beyond the scope of this contract to develop this information.

b. Injection Molded Items. Consideration of the materials for molding were made on glass-filled thermoplastics and epoxies. Glass-filled materials were chosen because of: 1) stability, 2) strength/weight,

3) fatigue. The materials investigated included: Polycarbonate, ABS, Delrin, Nylon and epoxy. Nylon was determined to have the highest strength-to-weight ratio but was rejected because of bondability, shrinkage, and water absorption. Delrin was rejected because of low strength/weight and poor bonding. In production, ABS would be selected for certain applications because of cost and Polycarbonate for the bulk of the applications because of high strength/weight, high impact strength, and fire retardance.

Compression-molded glass fiber epoxy was chosen for this program primarily because of lower tooling cost and the ability of molding the parts in-house.

c. Resin. The AFML (MAAE) statement of work requires the wing tank to be manufactured of fire-retardant materials. Fire retardance in epoxy resins has been a major effort with the epoxy manufacturers and formulators since the FAA directed the aircraft manufacturers to eliminate flammable products from aircraft design.

Several companies have been successful in developing fire-retardant epoxies; however, in most cases there has always been a compromise present. The addition of chlorine and bromine into standard epoxy systems (typically Chlorowax) gives some success at fire retardance but severely reduces resin strength properties. Dow Chemical Company has introduced a brominated epoxy resin with practically no loss in strength. The Dow material is a solid material at room temperature. For the type of high strength, wet filament winding necessary for this contract, the Dow material alone is no choice.

The Air Force Materials Laboratory is primarily responsible for the resin system or formulation proposed herein. The Dow self-extinguishing solid resin is blended with low viscosity liquid epoxies to achieve a winding viscosity of approximately 1,000 cps. at 120°F. Tests on samples and full scale aircraft water tanks wound with this formulation have given positive results. The specialty materials section at WPAFB has indicated that the blend, formulated as outlined, will meet or exceed the requirements of MIL-R-9300A.

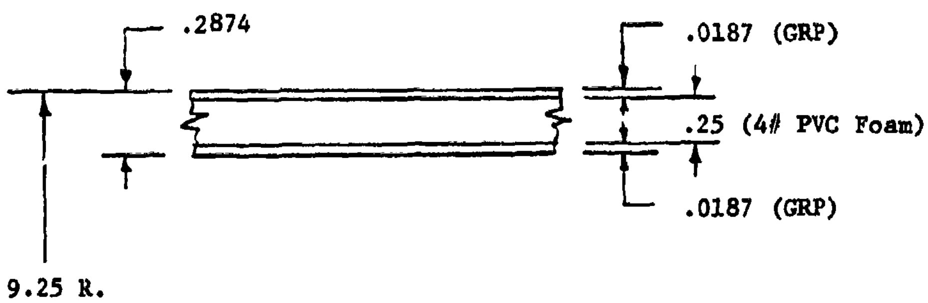
The application of filament windings directly to the ABS liner and the integral use of thermoplastic foam requires a resin cure at maximum temperatures not to exceed 250°F. The blend as outlined is cured at 180°F for two hours followed by four hours post cure at 250°F. The addition of BF_3MEA as an accelerator and the higher reactivity of the Dow resin combine, it is felt, to give a suitable cure at this lower temperature.

d. Glass. The types of glass which are commonly used for filament winding are "S" glass and "E" glass. "S" glass was used in this program primarily because of in-house availability in single-end, non-twisted roving; however, in production the choice would be "E" glass because of its lower cost.

3. STRUCTURAL ANALYSIS

a. Shell, Internal Pressure

The stresses caused by internal pressure are maximum on the cylindrical portion of the tank, where the wall thickness is a minimum and the membrane forces maximum. A cross section of the wall in the cylindrical portion of the tank is shown below:



The filament wound glass reinforced plastic (GRP) faces will each consist of one layer (2 plies) of both hoop and helical windings.

$$t_f = 4 \times .00467 = .0187 \text{ in. (See Appendix II)}$$

The average composite face stresses (hoop and helical oriented fibers) based on a netting analysis are:

$$\bar{R} = 9.25 - \frac{.2874}{2} = 9.1063 \text{ in.}$$

$$R_e = 3.68 \text{ in. (min. winding radius)}$$

$$\alpha_o = \sin^{-1}\left(\frac{3.68}{9.1063}\right) = 23.85^\circ$$

$$\sigma_\theta = \frac{P\bar{R}}{t_\theta}\left(1 - \frac{\tan^2\alpha_o}{2}\right) \quad \text{(hoop fiber composite stress)}$$

$$\sigma_\theta = \frac{200 \times 9.1063}{.0187}\left(1 - \frac{\tan^2 23.85}{2}\right) = 76{,}000 \text{ psi}$$

$$MS = \frac{129{,}700}{76{,}000} - 1 = 0.70$$

$$\sigma_\alpha = \frac{P\bar{R}}{2t_\alpha\cos^2\alpha_o} \quad \text{(helical fiber composite stress)}$$

$$\sigma_\alpha = \frac{200 \times 9.1063}{2 \times .0187 \times \cos^2 23.85} = 58{,}200 \text{ psi *}$$

$$MS = \frac{129{,}700}{58{,}200} - 1 = 1.23$$

* NOTE: These stresses are average values. Thick wall and sandwich wall core flexibility effects will both cause the stresses in the inside skin to increase slightly.

b. Shell, External Pressure

The critical external pressure (buckling) will be calculated assuming the section between the aft frame and tail cone joint to be a cylindrical shell 47.5 inches long.

The composite hoop and axial modulus of the helical plies are:

$$E_\theta = \frac{1}{\dfrac{\cos^2\alpha_o}{E_\perp} + \dfrac{\sin^2\alpha_o}{E//}} \qquad \text{(hoop modulus)}$$

$$E_\theta = \frac{10^6}{\dfrac{\cos^2 23.85}{1.5} + \dfrac{\sin^2 23.85}{6.04}} = 1.70 \times 10^6 \text{ psi} \quad \text{(See Appendix II)}$$

$$E_\chi = \frac{1}{\dfrac{\sin^2\alpha_o}{E_\perp} + \dfrac{\cos^2\alpha_o}{E//}} \qquad \text{(axial modulus)}$$

$$E_\chi = \frac{10^6}{\dfrac{\sin^2 23.85}{1.5} + \dfrac{\cos^2 23.85}{6.04}} = 4.02 \times 10^6 \text{ psi} \quad \text{(See Appendix II)}$$

The average composite modulus in the hoop and axial direction is:

$$\overline{E}_\theta = \left(\frac{6.04 + 1.70}{2}\right) 10^6 = 3.87 \times 10^6 \text{ psi}$$

$$\overline{E}_\chi = \left(\frac{1.50 + 4.02}{2}\right) 10^6 = 2.76 \times 10^6 \text{ psi}$$

The equivalent GRP composite used in the stability equation is:

$$\bar{E} = \frac{2\, E_\theta E_x}{E_\theta + E_x} \qquad \text{(Reference 6)}$$

$$\bar{E} = \frac{2 \times 3.87 \times 2.76 \times 10^6}{3.87 + 2.76} = 3.22 \times 10^6 \text{ psi}$$

The critical buckling pressure is:

$$P_{cr} = \frac{1}{R_o} \left\{ \frac{1}{\frac{1}{P_{cr}} + \frac{1}{U_{cr}}} \right\} \qquad \text{(Reference 2)}$$

$$P_{cr} = K \frac{3\bar{E}(t_c + t_f)^2 t_f}{2\, \bar{R}^2}$$

$$K = \frac{2.5\, \bar{R}}{L} \sqrt{\frac{\bar{R}}{t_c + t_f}}$$

$$U_{cr} = G_c \frac{(t + t_c)^2}{4\, t_c}$$

$$K = \frac{2.5 \times 9.1063}{47.5} \sqrt{\frac{9.1063}{.25 + .0187}} = 2.79$$

$$P_{cr} = 2.79 \frac{3 \times 3.22 \times 10^6 (.25 + .0187)^2\ .0187}{2 \times 9.1063^2} = 220 \text{ lbs/in}$$

$$U_{cr} = 2000 \frac{(.2874 + .25)^2}{4 \times .25} = 577 \text{ lbs/in.}$$

$$P_{cr} = \frac{1}{9.25} \left\{ \frac{1}{\frac{1}{220} + \frac{1}{577}} \right\} = 17.2 \text{ psi}$$

Ultimate external pressure "P_o" is:

$$P_o = 1.5 \times 3 = 4.5 \text{ psig}$$

$$MS = \frac{17.2}{4.5} - 1 = 2.82$$

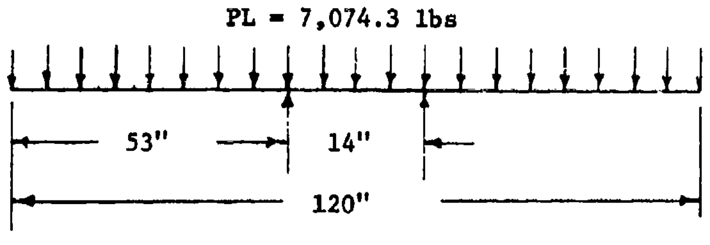
c. Shell, Flight Inertia

The tank will act as a beam to carry the inertia and/or air loads to its two internal frames where they are reacted. The ultimate store loads (taken from reference 1) acting at the C.G. are:

LOADING DIRECTION	WING STATION	
(CONDITION)	115.5	139.5
Down symmetrical	6,615.0	6,615.0
Up symmetrical	2,646.0	2,646.0
Down acc. roll	6,988.3	7,074.3
Down steady roll	5,292.0	5,292.0
Side steady roll	1,466.3	1,775.0

NOTE: The above loads are inertia only. Air loads subtract except for the side load and are in pounds.

The most critical condition is the down accelerated roll with the store at wing station 139.5. The maximum shear and bending moment is conservatively calculated assuming the free body diagram shown below.



$$P = \frac{7074.3}{120} = 59.0 \text{ lbs/in}$$

$$Q_{max} = 53 \times 59.0 = 3{,}130 \text{ lbs}$$

$$M_{max} = 3{,}130 \times \frac{53}{2} = 82{,}800 \text{ in/lbs}$$

Unit axial and shear loads:

$$\left.\begin{aligned} \bar{R} &= 9{,}106 \text{ in} \\ \Sigma t_f &= .0374 \text{ in} \\ t_c &= .25 \text{ in} \end{aligned}\right\} \quad \text{(see page 13)}$$

$$f = \frac{M}{\pi \bar{R}^2} = \frac{82{,}800}{\pi \times 9.106^2} = 318 \text{ lbs/in}$$

$$q = \frac{Q}{\pi \bar{R}} = \frac{3{,}130}{\pi \times 9.106} = 110 \text{ lbs/in}$$

The composite shell facing stresses are:

$$\sigma = \pm \frac{f}{\Sigma t_f} = \pm \frac{318}{.0374} = \pm 8{,}500 \text{ psi}$$

$$\tau = \frac{q}{\Sigma t_f} = \frac{110}{.0374} = 2{,}940 \text{ psi}$$

The critical buckling stresses with zero internal pressure are:

Bending (see reference 5)

$$\sigma_{cr} = .3 \; K_c \left(\frac{E_f \; (t_c + t_f)}{R \sqrt{\lambda}} \right)$$

$$K_c = 1 - .15H \qquad \text{when } H \leq .98$$

$$K_c = \frac{.834}{H} \qquad \text{when } H \geq .98$$

$$H = \frac{2 t_c t_f E_f}{3 \sqrt{\lambda} \; (t_c + t_f) \; R \; G_c}$$

$$\lambda = 1 - \mu_f^2$$

$$E_f = 3.22 \times 10^6 \text{ psi} \qquad \text{(see page 15)}$$

$$G_c = 2{,}000 \text{ psi}$$

$$R = 9.106 \text{ in.}$$

$$t_c = .25 \text{ in}$$

$$t_f = .0187 \text{ in}$$

$$\lambda = 1.0 \quad \text{(assume)}$$

$$H = \frac{2 \times .25 \times .0187 \times 3.22 \times 10^6}{3 \times 1\ (.25 + .0187)\ 9.106 \times 2{,}000} = 2.15$$

$$K_c = \frac{.834}{2.15} = .387$$

$$\sigma_{cr} = .3 \times .387 \left[\frac{3.22 \times 10^6 (.25 + .0187)}{9.106 \times 1} \right] = 11{,}000 \text{ psi}$$

<u>Torsional</u> (see reference 5)

$$\tau_{cr} = K_T \frac{E_f (t_c + 2t_f)}{R}$$

K_T (see figure 1 in reference 5)

$$S = \frac{t_c t_f E_f}{2\ \lambda_f (t_c + 2t_f)\ R\ G_c}$$

$$S = \frac{.25 \times .0187 \times 3.22 \times 10^6}{2 \times 1(.25 + 2 \times .0187)\ 9.106 \times 2{,}000} = 1.44$$

$$\frac{R}{t_c + 2t_f} = \frac{9.106}{.25 + 2 \times .0187} = 31.6$$

$$K_T = .12 \quad \text{(see figure 1 in reference 5)}$$

$$\tau_{cr} = .12 \left[\frac{3.22 \times 10^6 (.25 + 2 \times .0187)}{9.106} \right] = 12{,}200 \text{ psi}$$

Transverse Shear

The critical transverse shear buckling stress ranges from 1.25 to 1.6 times the critical torsional buckling stress. Conservatively assuming the 1.25 factor, the critical transverse shear stress is:

$$\tau_{cr} = 1.25 \times 12{,}200 = 15{,}200 \text{ psi}$$

Combined Bending and Transverse Shear

$$R_b + R_s^2 = 1 \qquad \text{(interaction eq.)}$$

$$\frac{8{,}500}{11{,}000} + \left(\frac{2{,}940}{15{,}200}\right)^2 = .809$$

$$MS \approx \frac{1}{.809} - 1 = .23$$

NOTE: The beam bending and shear stresses are low compared to the GRP's allowables.

d. Polar Rings (U.S. Polymeric E-7102)

The purpose of a polar ring is to carry the cover blow out load to the GRP windings. The geometry of the ring and its interaction with the cover are selected to minimize the bending caused by the loading eccentricity. The remaining moment will be mainly carried by the ring causing it to bend about its y-y axis.

The polar ring and cover geometry is shown in figure 2. The forces acting on the ring and the unbalanced moment they cause are:

Seal radius = 3.07 in.

$$P_1 = \pi \times 3.07^2 \times 200 \approx 5{,}910 \text{ lbs.}$$

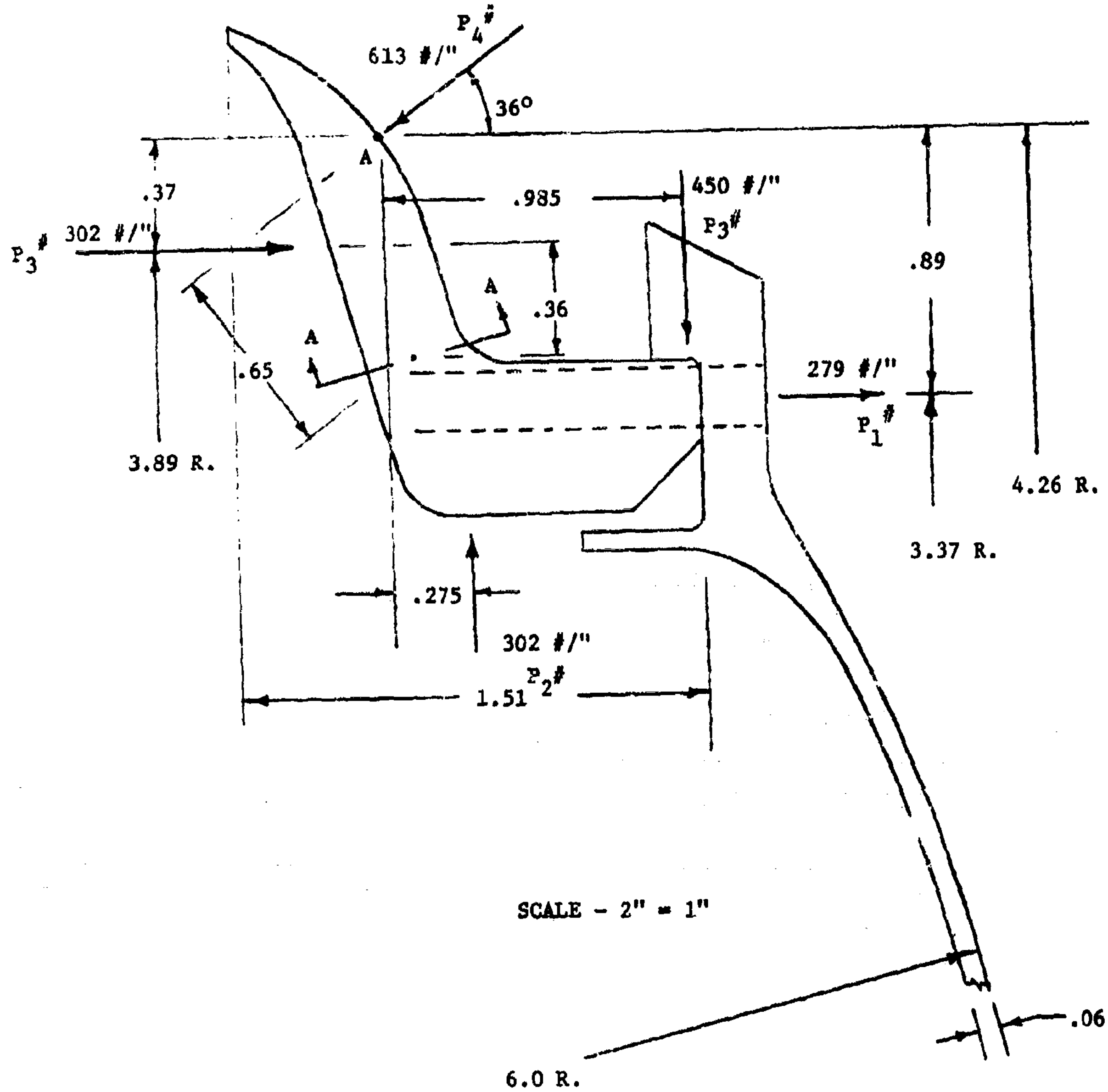


Figure 2. Polar Ring and Cover Geometry

$$P_1^* = \frac{5{,}910}{\pi \times 6.74} = 279 \text{ lbs/in}$$

$$P_2^* = 1.51 \times 200 = 302 \text{ lbs/in}$$

$$P_3 = \pi(4.6^2 - 3.07^2)200 = 7{,}370 \text{ lbs}$$

$$R_3 = \frac{2}{3}\left(\frac{4.6^3 - 3.07^3}{4.6^2 - 3.07^2}\right) = 3.89 \text{ in.}$$

$$P_3^* = \frac{7{,}370}{\pi \times 7.78} = 302 \text{ lbs/in}$$

$$P_4 = \frac{5{,}910 + 7{,}370}{\cos 36^\circ} = 16{,}400 \text{ lbs}$$

$$P_4^* = \frac{16{,}400}{\pi \times 8.52} = 613 \text{ lbs/in}$$

$$P_5 = \frac{\sqrt{6.00^2 - 3.07^2}}{3.07} \times 5{,}910 = 9{,}900 \text{ lbs}$$

$$P_5^* = \frac{9{,}900}{\pi \times 7.0} = 450 \text{ lbs/in}$$

The unbalanced moment (taking moments about pt. "A") is:

$$M^* = 279 \times .890 \times \frac{3.37}{4.26} = 196$$

$$+ \; 302 \times .275 \times \frac{3.00}{4.26} = 58$$

$$+ \; 302 \times .370 \times \frac{3.89}{4.26} = 102$$

$$- \; 450 \times .989 \times \frac{3.07}{4.26} = -321$$

$$\overline{+ \; 35^* \text{ in-lbs/in}}$$

The bending stress through section A-A, (see figure 2), is:

$$M = 613 \times .65 - 302 \times .36 = 280 \text{ in-lbs/in}$$

$$\sigma = \frac{6 \times 280}{.35^2} = 13{,}700 \text{ psi}$$

$$MS = \frac{25{,}000}{13{,}700} - 1 = 0.82$$

Twelve (12) 8-32 st. bolts (160 ksi H.T.) attach the cover to the polar ring:

$$\text{bolt spacing} = \frac{\pi \times 6.74}{12} = 1.765 \text{ in}$$

$$\text{load/bolt} = 1.765 \times 279 = 492 \text{ lbs}$$

$$\text{min.bolt area} = .0175 \text{ in}^2$$

$$\sigma = \frac{492}{.0175} = 28{,}100 \text{ psi}$$

$$M.S. = \frac{160{,}000}{28{,}100} - 1 = 4.70$$

* This value is very low, hence bending stresses are low by inspection.

e. <u>Covers</u> (Fiberite E-7111)

The covers will be 6.0 in. radius spherical segment 0.06 in. thick.

The membrane stress caused by 200 psig internal pressure is:

$$\sigma = \frac{200 \times 6.0}{2 \times .06} = 10,000 \text{ psi}$$

$$MS = \frac{25,000}{10,000} - 1 = 1.5$$

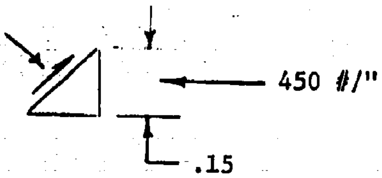
The critical external (buckling) pressure for the covers is:

$$P_{cr} = 0.80 \, E\left(\frac{t}{R_o}\right)^2 \qquad \text{(reference 3)}$$

$$P_{cr} = 0.80 \times 1.2 \times 10^6 \left(\frac{0.06}{6.0}\right)^2 = 96 \text{ psi}$$

$$MS = \frac{96}{4.5} - 1 = 20.3$$

The shear stress in the covers shear lip is:



$$\tau = \frac{450 \times .707^2}{.15} = 1,500 \text{ psi}$$

$$MS = \frac{12,000}{1,500} - 1 = 7.0$$

f. Fins and Tail Cone

The fins and tail cone are proposed to be a one-piece, sandwich-wall construction having GRP faces and a foam core. The core will be locally reinforced in the juncture area (fins to tail conc).

The fins are required to support a 200 pound normal force applied at each tip simultaneously or individually.

To simplify the analysis, the fins are idealized as a cantilever beam of rectangular cross section.

L_e = 11.5 in. (effective fin length)

D_e = 12.0 in. (equivalent fin width)

The maximum unit moment and shear are:

$$M = \frac{PLe}{D_e}, \quad Q = \frac{P}{D_e}$$

$$M = \frac{200 \times 11.5}{12.0} = 192 \text{ in-lbs/in}$$

$$Q = \frac{200}{12} = 16.7 \text{ lbs/in}$$

The fins faces will each consist of two plies, style 181 E glass/epoxy ($t = 0.02$). The core will be 0.69 inch thick, 4 lb/ft^3 density foam.

The bending stress in the faces is:

$$\sigma = \frac{192}{.71 \times .02} = 13{,}500 \text{ psi}$$

$$MS = \frac{44{,}000}{13{,}500} - 1 = 2.26$$

The critical face wrinkling stress is:

$$F_{cr} = 0.5\left(\frac{E_f E_c G_c}{\lambda_f}\right)^{1/3}$$

$$F_{cr} = 0.5\left(\frac{2.5 \times 10^6 \times 6{,}000 \times 2{,}000}{1 - .12^2}\right)^{1/3} = 15{,}600 \text{ psi}$$

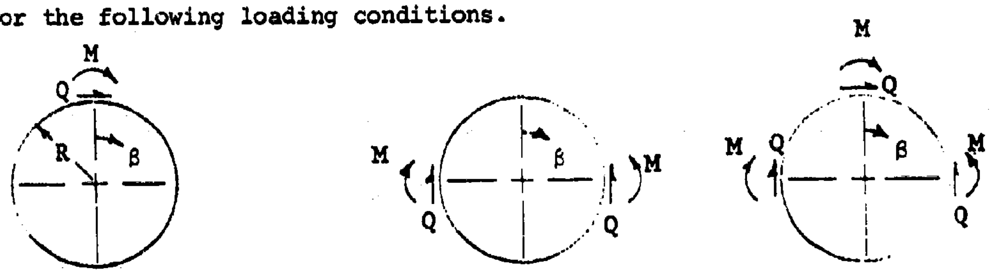
$$MS = \frac{15{,}600}{13{,}500} - 1 = .16$$

The core shear stress is:

$$\tau = \frac{16.7}{.69} = 24 \text{ psi}$$

$$MS = \frac{125}{24} - 1 = 4.20$$

The tail cone will also be sandwich wall construction, $t_f = 0.020$ GRP, $t_c = .69$ cone radius of 3.5 inches. The tail cone is analyzed as a frame for the following loading conditions.



COND. I COND. II COND. III

M = 192 in-lbs./in.

Q = 16.7 lbs./in.

R = 3.5 in.

$$I = \frac{.73^3 - .69^3}{12} = .0060 \text{ in}^4$$

$$E = 2.5 \times 10^6 \text{ psi}$$

Tables IV, V, and VI show the results of the frame analysis for Conditions I, II, and III respectively.

TABLE IV

E= .2500+07
R= 3.5000
I= .00778

FRAME ANALYSIS - COND. I

GAMMA DEGREES	RADIAL LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB
.00	-.00	200.00	192.00

BETA DEGREES	SHEAR LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB	DEFLECTION (IN)
.00	-73.94	-100.00	96.00	.00003
10.00	-57.03	-93.28	56.06	.00111
20.00	-41.52	-84.06	26.04	.00094
30.00	-27.80	-72.94	4.96	.00018
40.00	-16.14	-60.58	-8.35	-.00069
50.00	-6.69	-47.61	-15.20	-.00138
60.00	.48	-34.67	-16.98	-.00173
70.00	5.45	-22.35	-15.06	-.00170
80.00	8.35	-11.17	-10.75	-.00130
90.00	9.44	-1.55	-5.23	-.00064
100.00	9.00	6.20	.47	.00016
110.00	7.40	11.85	5.53	.00096
120.00	4.99	15.33	9.35	.00163
130.00	2.17	16.67	11.55	.00206
140.00	-.71	16.03	11.99	.00217
150.00	-3.32	13.66	10.74	.00194
160.00	-5.40	9.91	8.04	.00143
170.00	-6.73	5.20	4.29	.00074
180.00	-7.18	-.00	-.00	.00010
190.00	-6.73	-5.20	-4.30	-.00074
200.00	-5.40	-9.91	-8.04	-.00143
210.00	-3.32	-13.66	-10.74	-.00194
220.00	-.71	-16.03	-11.99	-.00217
230.00	2.17	-16.67	-11.55	-.00206
240.00	4.99	-15.33	-9.35	-.00163
250.00	7.40	-11.85	-5.53	-.00096
260.00	9.00	-6.20	-.47	-.00016
270.00	9.44	1.55	5.23	.00064
280.00	8.35	11.17	10.75	.00130
290.00	5.45	22.35	15.06	.00170
300.00	.48	34.67	16.98	.00173
310.00	-6.69	47.61	15.20	.00138
320.00	-16.14	60.58	8.35	.00069
330.00	-27.80	72.94	-4.96	-.00018
340.00	-41.52	84.06	-26.04	-.00094
350.00	-57.03	93.28	-56.06	-.00111
360.00	-73.94	100.00	-96.00	-.00003

TABLE V

E= .2500+07 FRAME ANALYSIS - COND. II
R= 3.5000
I= .00778

GAMMA DEGREES	RADIAL LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB
90.00	-.00	-200.00	-192.00
270.00	-.00	200.00	192.00

BETA DEGREES	SHEAR LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB	DEFLECTION (IN)
.00	-.00	-3.09	-10.46	-.00128
10.00	.65	-4.97	-10.27	-.00114
20.00	1.95	-10.51	-9.53	-.00073
30.00	4.51	-19.34	-7.64	-.00010
40.00	8.86	-30.94	-3.66	.00068
50.00	15.43	-44.55	3.64	.00148
60.00	24.48	-59.28	15.70	.00212
70.00	36.13	-74.14	34.08	.00236
80.00	50.30	-88.08	60.35	.00185
90.00	66.75	100.00	-96.00	.00008
100.00	50.30	88.08	-60.35	-.00185
110.00	36.13	74.14	-34.08	-.00236
120.00	24.48	59.28	-15.70	-.00212
130.00	15.43	44.55	-3.64	-.00148
140.00	8.86	30.94	3.65	-.00068
150.00	4.51	19.34	7.64	.00010
160.00	1.95	10.51	9.53	.00073
170.00	.65	4.97	10.27	.00114
180.00	.00	3.09	10.46	.00128
190.00	-.65	4.97	10.27	.00114
200.00	-1.95	10.51	9.53	.00073
210.00	-4.51	19.34	7.64	.00010
220.00	-8.86	30.94	3.66	-.00068
230.00	-15.43	44.55	-3.64	-.00148
240.00	-24.48	59.28	-15.70	-.00212
250.00	-36.13	74.14	-34.08	-.00236
260.00	-50.30	88.08	-60.35	-.00185
270.00	-66.75	-100.00	96.00	-.00008
280.00	-50.30	-88.08	60.35	.00185
290.00	-36.13	-74.14	34.08	.00236
300.00	-24.48	-59.28	15.70	.00212
310.00	-15.43	-44.55	3.64	.00148
320.00	-8.86	-30.94	-3.65	.00068
330.00	-4.51	-19.34	-7.64	-.00010
340.00	-1.95	-10.51	-9.53	-.00073
350.00	-.65	-4.97	-10.27	-.00114
360.00	-.00	-3.09	-10.46	-.00128

TABLE VI

E= .2500+07 **FRAME ANALYSIS - COND. III**
R= 3.5000
I= .00778

GAMMA DEGREES	RADIAL LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB
.00	-.00	200.00	192.00
90.00	-.00	200.00	192.00
270.00	-.00	200.00	192.00

BETA DEGREES	SHEAR LOAD LB	TANGENTIAL LOAD LB	MOMENT IN-LB	DEFLECTION (IN)
.00	-55.06	-100.00	96.00	.00003
10.00	-39.67	-75.91	67.28	.00257
20.00	-28.68	-49.85	46.63	.00360
30.00	-22.32	-22.94	31.29	.00355
40.00	-20.65	3.70	18.40	.00275
50.00	-23.54	29.00	5.13	.00147
60.00	-30.64	51.93	-11.21	.00002
70.00	-41.47	71.62	-33.06	-.00121
80.00	-55.40	87.31	-62.51	-.00167
90.00	-71.69	-101.55	90.77	-.00051
100.00	-54.76	-92.29	52.23	.00052
110.00	-39.52	-82.12	23.53	.00048
120.00	-26.13	-71.27	3.57	-.00012
130.00	-14.67	-59.93	-8.79	-.00080
140.00	-5.23	-48.25	-14.76	-.00127
150.00	2.16	-36.34	-15.60	-.00143
160.00	7.45	-24.29	-12.56	-.00124
170.00	10.63	-12.16	-6.93	-.00072
180.00	11.69	-.00	-.00	.00010
190.00	10.63	12.16	6.92	.00072
200.00	7.45	24.29	12.55	.00124
210.00	2.16	36.34	15.59	.00143
220.00	-5.23	48.25	14.76	.00127
230.00	-14.67	59.93	8.79	.00080
240.00	-26.13	71.27	-3.57	.00012
250.00	-39.52	82.12	-23.53	-.00048
260.00	-54.76	92.29	-52.24	-.00052
270.00	-71.69	-98.45	101.23	.00077
280.00	-55.40	-87.31	62.51	.00167
290.00	-41.47	-71.62	33.06	.00121
300.00	-30.64	-51.93	11.21	-.00002
310.00	-23.54	-29.00	-5.13	-.00147
320.00	-20.65	-3.70	-18.41	-.00275
330.00	-22.32	22.94	-31.30	-.00355
340.00	-28.68	49.86	-46.63	-.00360
350.00	-39.67	75.91	-67.28	-.00257
360.00	-55.06	100.00	-96.00	-.00003

The maximum bending stress in the tail cone is:

$$M = 101.23 \text{ in-lbs/in} \qquad (\text{see page } 29,\ \beta = 270^{\circ})$$

$$\sigma = \frac{101.23}{.71 \times .02} = 7{,}120 \text{ psi}$$

$$MS = \frac{44{,}000}{7{,}120} - 1 = 5.17$$

The maximum shear stress in the tail cone is:

$$Q = 73.94 \text{ lbs/in} \qquad (\text{see page } 27,\ \beta = 0^{\circ})$$

$$\tau = \frac{73.94}{.69} = 107 \text{ psi}$$

$$MS = \frac{125}{107} - 1 = .17$$

In the juncture area (fin to tail cone), the 4 lb/ft^3 foam will be replaced with 31.2 lb/ft^3 ABS foam. The bending and shear stresses in the foam are:

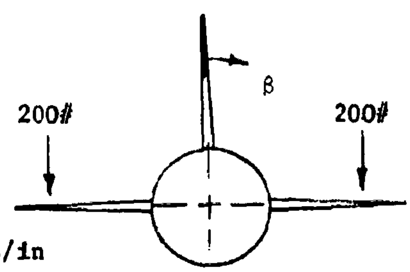
$$\sigma = \frac{6 \times 192}{.69^2} = 2{,}410 \text{ psi}$$

$$MS = \frac{2{,}400}{2{,}410} - 1 = 0$$

$$\tau = \frac{16.7}{.69} = 24.2 \text{ psi}$$

$$MS = \text{HIGH}$$

The tail cone to tank attachment loads are:



$$q = \frac{Q}{\pi R} \sin\beta \qquad (\text{lbs/in})$$

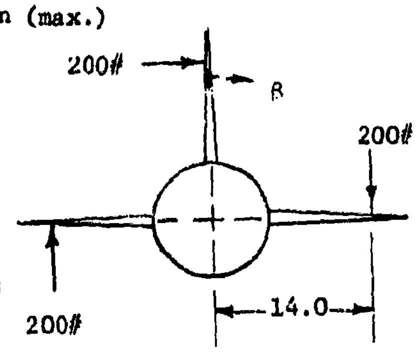
$$q = \frac{400}{\pi \times 5.0} \sin\beta = 25.5 \sin\beta \text{ lbs/in}$$

$L = 12.0$ in

$M = 400 \times 12.0 = 4{,}800$ in-lbs

$$f = \frac{M}{\pi R^2} \cos\beta \quad \text{(lbs/in)}$$

$$f = \frac{4{,}800}{\pi \times 5.0^2} \cos\beta = 61.2 \text{ lbs/in (max.)}$$



$$q = \frac{T_y}{2\pi R^2} + \frac{Q}{\pi R} \cos\beta$$

$T_y = 3 \times 200 \times 14.0 = 8{,}400$ in-lbs

$Q = 200$ lbs

$$q = \frac{8{,}400}{2 \times \pi \times 5.0^2} + \frac{200}{\pi \times 5.0} \cos\beta = 53.5 + 12.75 \cos\beta$$

$$= 66.25 \text{ lbs/in (max.)}$$

g. Internal Frames

The frame design consists of a rectangular box section located inside the tank. The frame depth varies from a maximum at the point of load to a minimum at 180 degrees from the point of load by tapering the core thickness to zero at 180 degrees. The box section is fabricated with 181 cloth and hoop fibers. The inside and outside skins contain 181 cloth interspersed with filament wound hoop fibers, and the side skins contain 181 cloth. (See Figure 3.)

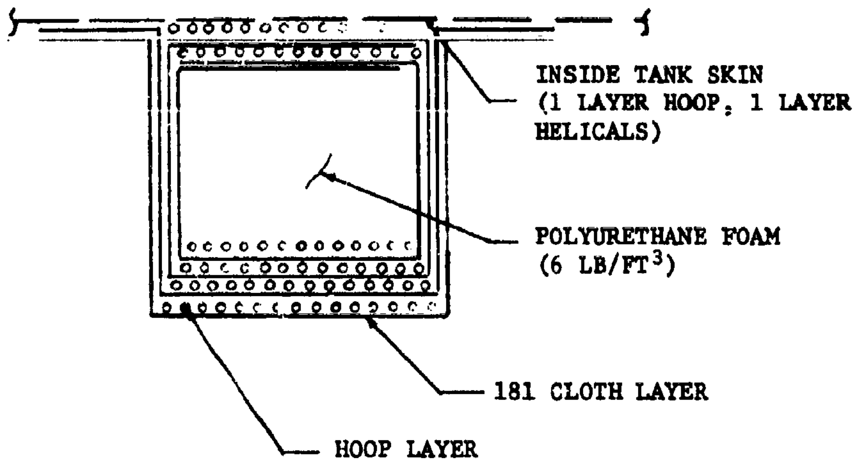


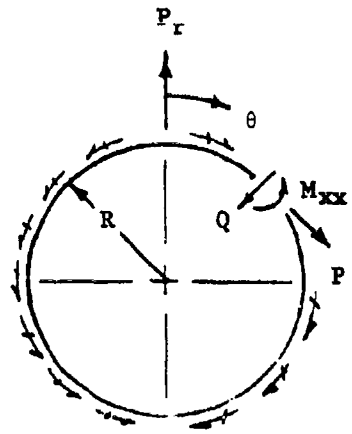
Figure 3. Typical Frame Cross-Section

The polyurethane foam core is laid in place prior to forming the mandrel and winding the tank.

The in-plane frame loads are calculated using a standard frame analysis. This analysis is modified slightly to account for the non-uniform cross-section by assuming the frame will not carry bending at 180 degrees from the point of loading. This is slightly unconservative at 180 degrees from the point of the applied radial load; however, it is conservative as we approach the point of the applied load where the stresses are maximum

The equations used to evaluate the internal frame loads caused by a radial load "P_r" and reacted by shear loads in a sine distribution are summarized below:

$$q_\theta = \frac{P_r}{\pi R} \sin\theta$$



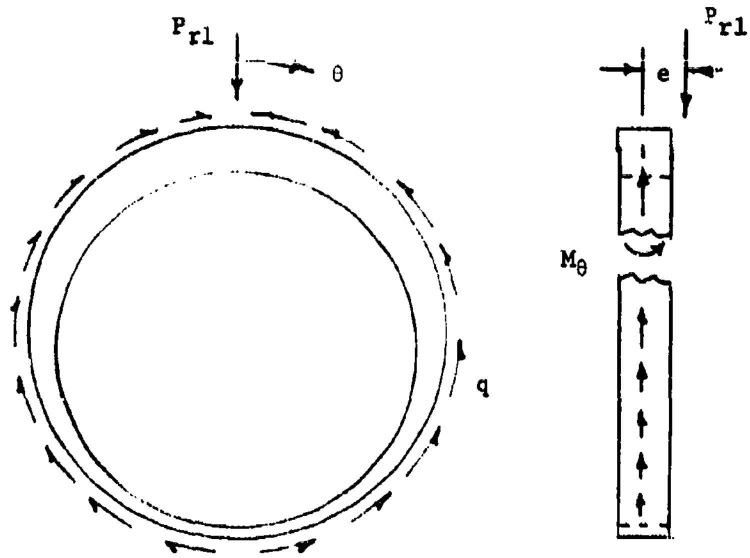
$$M_{xx} = \frac{P_r R}{2\pi}\left[(\pi - \theta)\sin\theta - \tfrac{1}{2}\cos\theta - 1\right] + .08\, P_r R$$

$$P = \frac{P_r}{2\pi}\left[\frac{3}{2}\cos\theta + (\pi - \theta)\sin\theta\right]$$

$$Q = \frac{P_r}{2\pi}\left[(\pi - \theta)\cos\theta - \tfrac{1}{2}\sin\theta\right]$$

The sway brace load does not act at the center of the frame, and, therefore, causes bending about the y-y axis and torsion in the frame.

The bending "M_θ" caused by the eccentricity of the sway brace load is:



At $\theta = 0^\circ$

$$M_\theta = \left(\frac{P_{r1}}{2}\right) e$$

Shear at any point:

$$q = \frac{P_{r1}\sin\theta}{\pi R} = q_m \sin\theta$$

The bending at any point is:

$$M_\theta = \frac{P_{r1}e}{2} - \int_0^\theta e\ R\ q_m \sin^2\theta\ d\theta$$

$$M_\theta = \frac{P_{r1}e}{2} - e\ R\ q_m\left[\frac{\theta}{2} - \frac{1}{4}\sin 2\theta\right]_0^\theta$$

$$M_\theta = P_{r1}e\left(\frac{1}{2} - \frac{\theta}{2\pi} - \frac{1}{4\pi}\sin 2\theta\right)$$

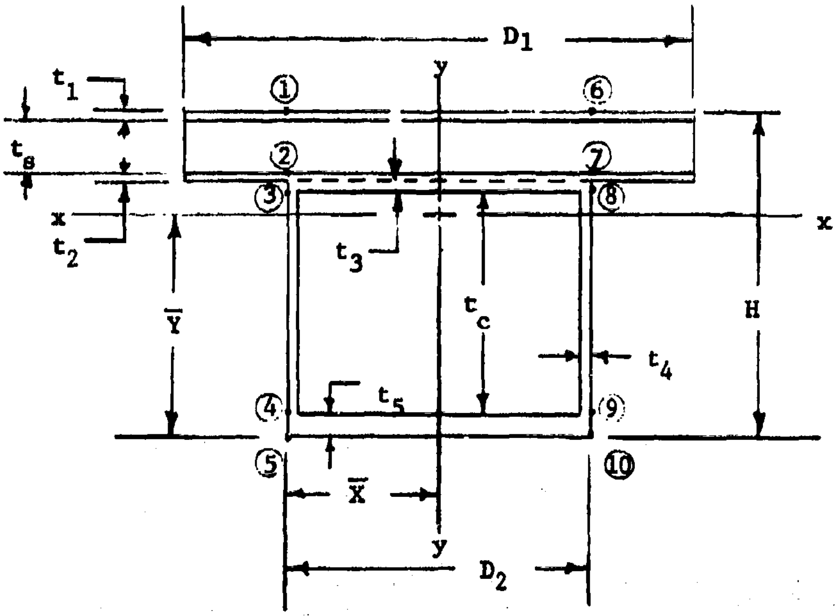
The bending about the y-y axis and torsion at any point becomes:

$$M_{yy} = M_\theta \sin\theta$$

$$T_y = M_\theta \cos\theta$$

FRAME STRESSES

The frame stresses are calculated for the following frame configuration:



Stresses due to M_{xx} (stresses are based on a base modulus, E_B):

$$S_{1,6} = \frac{M_{xx}(H-\overline{Y})}{I_{xx}}$$

$$S_{2,7} = \frac{M_{xx}(H - \overline{Y} - t_1 - t_s)}{I_{xx}}$$

$$S_{3,8} = \frac{M_{xx}(t_c + t_5 - \overline{Y})}{I_{xx}}$$

$$S_{4,9} = \frac{M_{xx}(\overline{Y} - t_5)}{I_{xx}}$$

$$S_{5,10} = \frac{M_{xx}\,\overline{Y}}{I_{xx}}$$

Stresses due to P:

$$S_p = \frac{P}{A} \quad \text{(at all points)}$$

Stresses due to M_{yy}:

$$S_{my} = \pm \frac{M_{yy}\,\overline{X}}{I_{yy}} \qquad (-\text{ for points 1-5, + for points 6-10})$$

Total stresses at points 1 through 10:

$$\sigma_1 = (-S_{my} - S_1 + S_p)\,\frac{E_1}{E_B}$$

$$\sigma_6 = (\;S_{my} - S_1 + S_p)\,\frac{E_1}{E_B}$$

$$\sigma_2 = (-S_{my} - S_2 + S_p)\,\frac{E_2}{E_B}$$

$$\sigma_7 = (\;S_{my} - S_2 + S_p)\,\frac{E_2}{E_B}$$

$$\sigma_3 = (-S_{my} - S_3 + S_p)\,\frac{E_4}{E_B}$$

$$\sigma_8 = (\;S_{my} - S_3 + S_p)\,\frac{E_4}{E_B}$$

$$\sigma_4 = (-S_{my} + S_4 + S_p)\,\frac{E_4}{E_B}$$

$$\sigma_9 = (\;S_{my} + S_4 + S_p)\,\frac{E_4}{E_B}$$

$$\sigma_5 = (-S_{my} + S_5 + S_p)\,\frac{E_4}{E_B}$$

$$\sigma_{10} = (\;S_{my} + S_5 + S_p)\,\frac{E_4}{E_B}$$

Shear stress in web:

$$\tau_w = \frac{q_{ct}}{2t_4} + \frac{q_{cv}}{2t_4}\left(\frac{2t_4G_4}{2t_4G_4 + (D_2 - 2t_4)\ G_c}\right)$$

Shear stress in frame core:

$$\tau_c = \frac{q_{cv}}{D_2 - 2t_4}\left(\frac{(D_2 - 2t_4)\ G_c}{(D_2 - 2t_4)\ G_c + 2t_4\ G_4}\right)$$

Shear stress in shell core:

$$\tau_s = \frac{2q_{st} + q_{sv}}{D_1}$$

WHERE:

$$A_1 = t_1D_1E_1/E_B$$

$$A_4 = 2t_4t_cE_4/E_B$$

$$A_5 = t_5D_2E_5/E_B$$

$$Q_s = A_1\left(H - \overline{Y} - \frac{t_1}{2}\right)$$

$$Q_c = A_5\left(\overline{Y} - \frac{t_5}{2}\right) + t_4\left(\overline{Y} - t_5\right)^2E_4/E_B \quad \text{if } \overline{Y} < t_c + t_5$$

$$Q_c = A_5\left(\overline{Y} - \frac{t_5}{2}\right) + A_4\left(\overline{Y} - \frac{t_c}{2} - t_5\right) \text{ if } \overline{Y} > t_c + t_5$$

$$A_c = \left(D_2 - t_4\right)\left(t_c + \frac{t_3}{2} + \frac{t_5}{2}\right)$$

$$t_e = \frac{G_s}{G_1}\ \frac{D_1}{2}$$

$$A_s = \left(t_s + \frac{t_1}{2} + \frac{t_2}{2}\right)\frac{D_1}{2}$$

$$\delta_{cc} = \frac{2t_c}{t_4} + \frac{D_2}{t_5} + \frac{D_2}{t_3}$$

$$\delta_{ss} = \frac{2t_s}{t_e} + \frac{D_1}{2t_1} + \frac{D_1}{2t_2}$$

$$\delta_{cs} = \frac{D_2}{t_2 + t_3}$$

$$q_{ct} = \frac{T_y}{2}\left(\frac{A_c\delta_{ss} + A_s\delta_{cs}}{A_c^2\delta_{ss} + 2A_cA_s\delta_{cs} + A_s^2\delta_{ss}}\right)$$

See page 492 of reference 4.

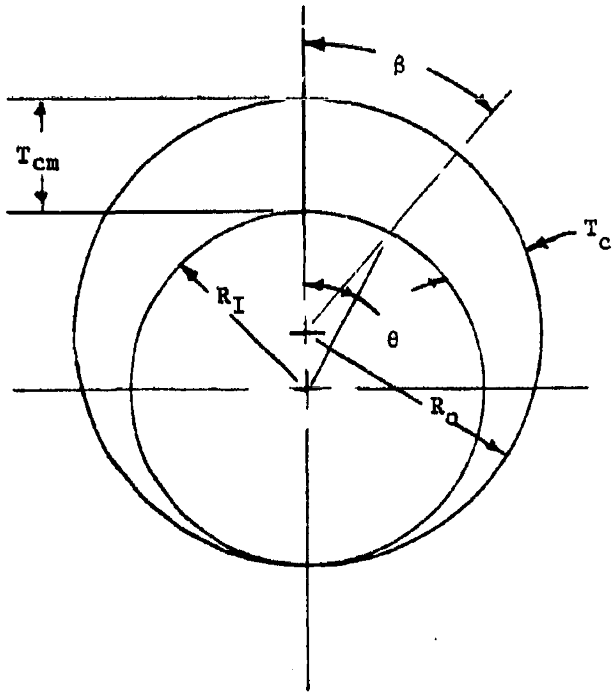
$$q_{st} = \frac{T_y}{2}\left(\frac{A_s\delta_{cc} + A_c\delta_{cs}}{A_c^2\delta_{ss} + 2A_cA_s\delta_{cs} + A_s^2\delta_{ss}}\right)$$

$$q_{cv} = \frac{Q\,Q_c}{I_{xx}}$$

$$q_{sv} = \frac{Q\,Q_s}{I_{xx}}$$

The above equations were programmed in the FORTRAN IV language and several cases were run on the computer to determine the stresses at any point around the frame. The computer runs are shown in the supplement.

The thickness of the core at any angle β is calculated from the equation below.



$$T_c = R_o - \frac{R_I \sin \theta}{\sin \beta}$$

WHERE:

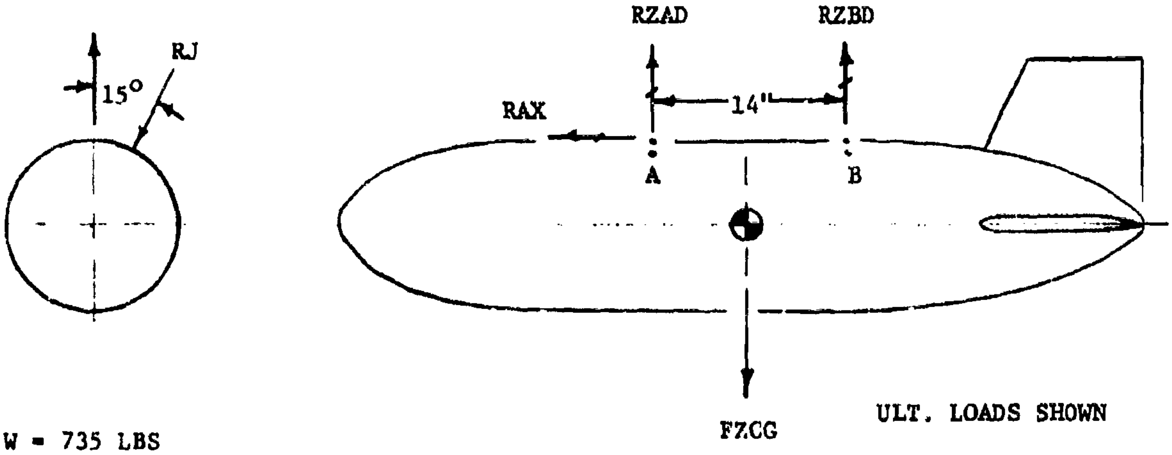
$$\theta = \beta - \sin^{-1}\left(\frac{T_{cm} \sin\beta}{2R_I}\right)$$

The loads on the forward and aft attach points are summarized on page 40. A summary of the maximum stresses for each loading condition is shown in Table VIII on page 41. These stresses were summarized from the computer output in the supplement.

TABLE VII

FRAME LOADS

STORE NO. 2



W = 735 LBS

ULT. LOADS SHOWN

WING STA. 139.50

COND.	*	RZAD	RJ	RZBD	RJ	RAX
6.0 G sym. man.	(I + A)	4,075.6	594.0	3,770.4	594.0	230.8
-2.4 G sym. man.	(I)	0	719.0	0	656.0	-92.3
acc. roll	(I)	3,698.2	0	3,371.8	0	248.8
steady roll	(I + S.L.)	6,134.9	3,240.0 ①	5,890.7	3,240.0 ③	184.6
1.0 G rudder ind.	(I + S.L.)	2,100.3	1,466.0	2,049.4	1,466.0	38.5

WING STA. 115.50

COND.	*	RZAD	RJ	RZBD	RJ	RAX
6.0 G sym. man.	(I + A)	4,104.1	621.0 ②	3,798.8	621.0 ④	230.9
-2.4 G sym. man.	(I)	0	719.0	0	656.0	-92.3
acc. roll man.	(I)	3,653.3	0	3,330.8	0	243.9
steady roll	(I + S.L.)	5,549.2	2,676.0	5,304.9	2,676.0	184.7
Received from Air Force Systems Command		5,785.0	3,340.0 ⑤	4,648.0	2,009.0 ⑦	
		4,946.0	411.0 ⑥	6,810.0	4,938.0 ⑧	

NOTE: Ult = 1.5 (limit)

The conditions underlined were analyzed as the condition circled. The frame stresses are summarized in Table VIII, page 41.

* I = Inertia Load
A = Air Load
S.L. = Side Load

TABLE VIII

FRAME STRESS SUMMARY

	LOADING CONDITION							
	1	2	3	4	5	6	7	8
Applied Load	6,135	4,104	5,891	3,798	5,785	4,946	4,648	6,810
Sway Brace Load	3,240	621	3,240	621	3,340	411	2,009	4,938
BENDING STRESS								
1. Outside Skin	-10,471	-15,493	10,171	-14,145	9,225	-20,813	-10,239	19,213
2. Inside Skin	6,731	-6,834	6,559	-6,327	6,200	-8,877	-5,692	7,026
3. Web at Top	5,339	-4,648	5,208	-4,329	4,915	-6,055	4,316	5,571
4. Web at Bottom	10,173	11,948	9,747	10,959	8,899	15,646	9,196	-9,540
5. Lower Frame Skin	14,586	17,450	13,941	15,999	12,699	23,157	13,265	-14,905
SHEAR STRESS								
6. Web *	9,681	9,190	10,269	8,653	8,629	11,667	8,816	12,652
7. Frame Core	42	22	41	21	41	27	30	52
8. Shell Core	168	110	204	108	178	136	132	330

* Only shear stresses past the frame attachment fitting are shown since the stresses above this point are carried by the molar and are actually much lower than shown in the computer output.

h. <u>Frame Attachment Fitting</u> (USP 7102 Mold. Comp.)

The frame attachment fitting is bonded inside the frame GRP skin. The attachment lug and sway brace shoes feed their loads directly into this fitting which in turn distributes the load to the frame. In the region between the lug and sway brace contact point, this fitting reinforces the basic frame.

The nut shear out stress caused by a tension force of 6,810.0 pounds, (maximum lug tension load, see page 40) is:

$$\tau = \frac{6{,}810.0}{\pi \times 1.0 \times .75} = 2{,}890 \text{ psi}$$

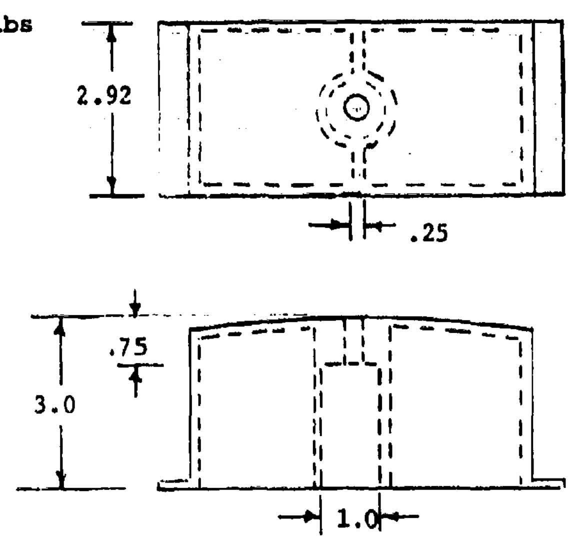
$$MS = \frac{12{,}000}{2{,}890} - 1 = 3.02$$

The maximum bending stress in the beam between the fitting sides is:

$$M = \frac{6{,}810.0 \times 2.92}{4} = 4{,}970 \text{ in-lbs}$$

$$\sigma = \frac{6 \times 4{,}970}{.25 \times 3.0^2} = 13{,}240 \text{ psi}$$

$$MS = \frac{25{,}000}{13{,}240} - 1 = .89$$



The sway brace kick load is more eccentric to the frame center line on the aft frame. The column stress in the fitting corner and the shear flow (fitting to frame skin) is:

$$P = 4{,}938 \text{ lbs} \qquad \text{(see page 40)}$$

$$\sigma = \frac{4{,}938}{.15 \times 1.5} = -21{,}900 \text{ psi}$$

$$MS = \frac{37{,}000}{21{,}900} - 1 = .69$$

$$e = 1.75 \text{ in}$$

$$q = \frac{1.75 \times 4{,}938}{2 \times 2.92 \times 3.0} + \frac{4{,}938}{2 \times 3.0} = 1{,}314 \text{ lbs/in}$$

Assume 1/2 inch bond width is effective:

$$\tau_{bond} = \frac{1{,}314}{.5} = 2{,}628 \text{ psi}$$

$$MS = \frac{3{,}000}{2{,}628} - 1 = .14$$

4. WEIGHT SUMMARY

STRUCTURAL SHELL COMPLETE WITH INTERNAL SUPPORT RINGS, NOSE, TAIL, AND RELATED STRUCTURES.

LESS: INTERNAL PLUMBING, FITTINGS, AND RELATED HARDWARE.

Calculated Breakdown

ABS liner (one piece formed)	5.5 pounds
Polar rings	1.6
End closures	.4
Nose fairing cone	.4
Internal support rings	6.3
Molars	2.0
Windings (glass and resin)	23.2
Foam shell	3.5
Tail fin assembly	5.5
Total tank weight:	48.4 pounds

SECTION V

FABRICATION AND TOOLING

There are six subassemblies which make up the wing tank. Figure 4 shows the subassembly breakdown.

1) Frames. The frames each consist of a compression-molded molar, two internal premolded urethane foam sections, a GRP laminate and two foamed-in-place radius rings.

   a. The molar is compression molded, its outer surface sandblasted, the lug attachment nut bonded in place and the remaining inside molar cavity filled with urethane foam, foamed-in-place.

      Figure 5 shows the tooling used for molding the molar.

      Figure 6 shows two molars as molded.

      Figure 7 shows a molar which has been sawed in half to show its inner construction.

   b. The urethane foam components which go inside the frames' GRP laminate are molded.

      Figure 8 shows foam mold and a completed foam component.

   c. Laminate the frame in a split female tool. The laminate is a combination of hand-laid up style 181 fabric and circumferential wound glass rovings/epoxy. The foam components and molar are inserted in place prior to laminating the outside surface of the frames. The radius rings are foamed in place after the GRP laminate is cured.

      Figure 9 shows the frame tool.

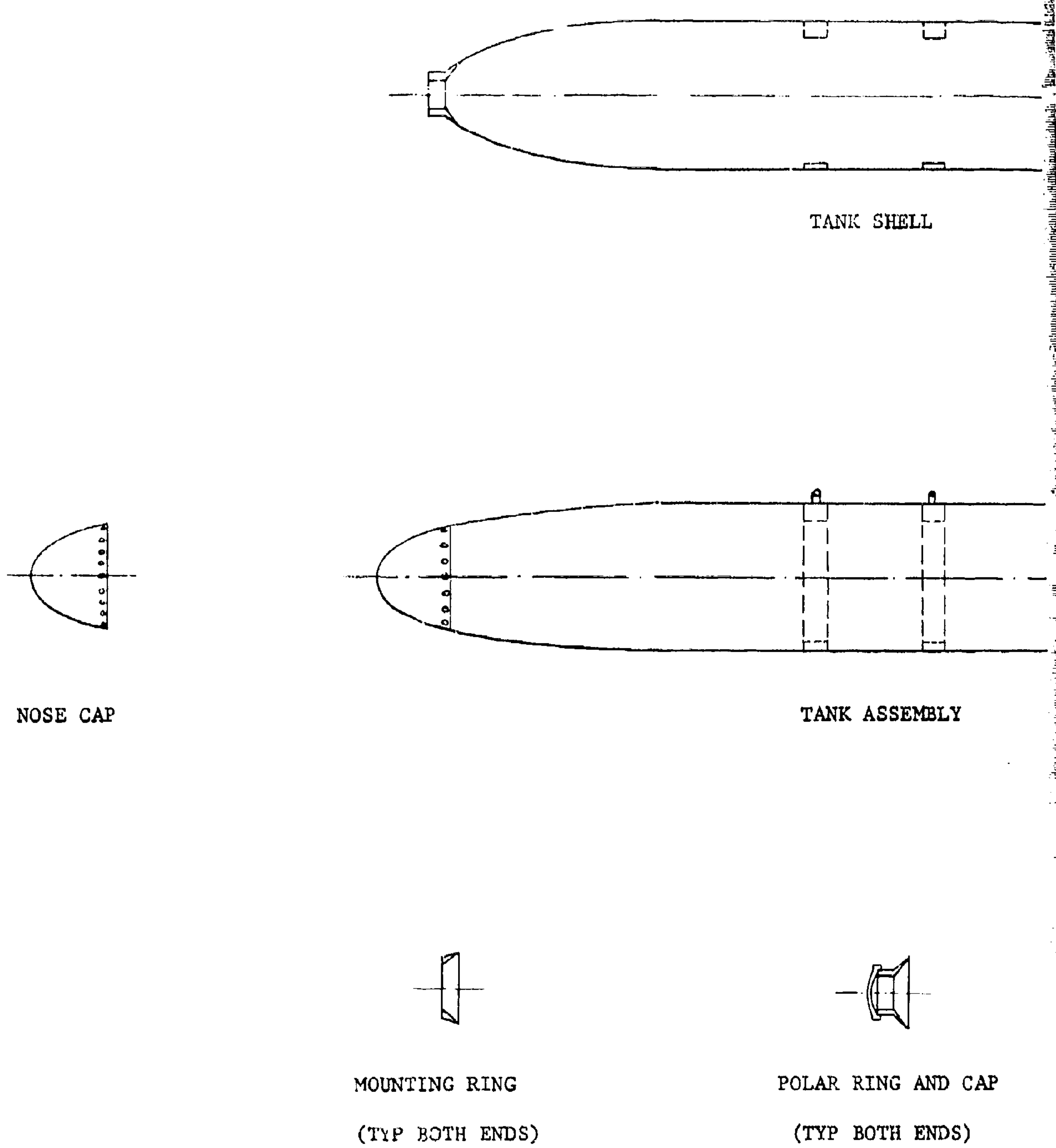
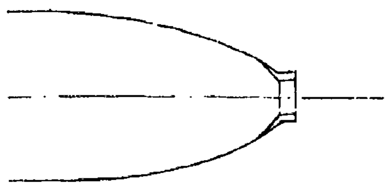
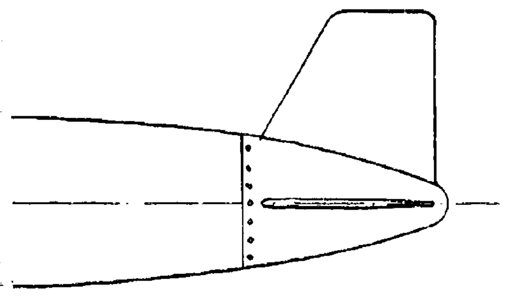
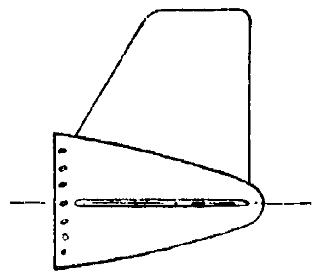


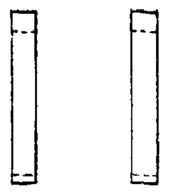
Figure 4. Tank Subassembly Breakdown







TAIL FINS



FRAMES

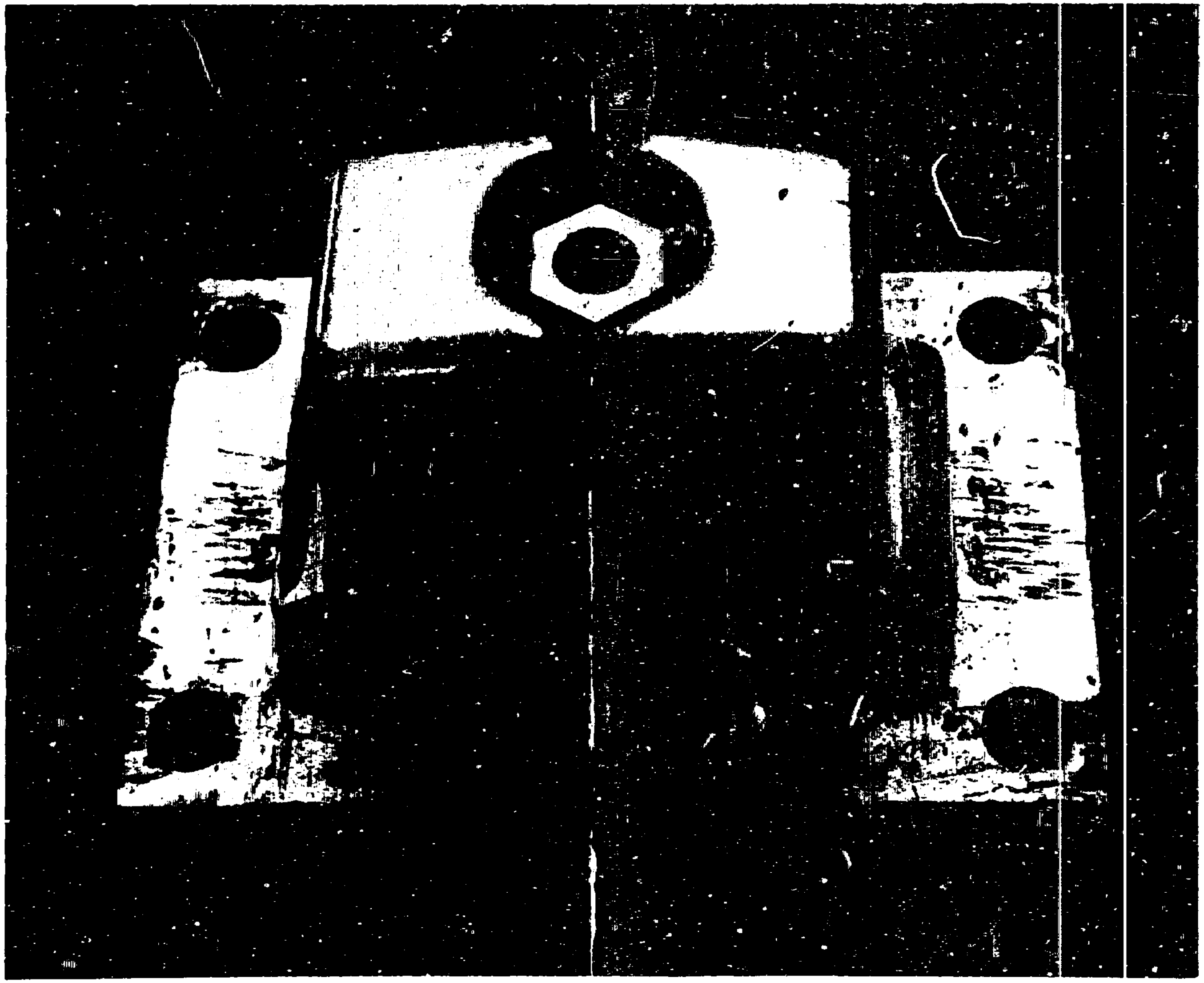


Figure 5. Molar Mold

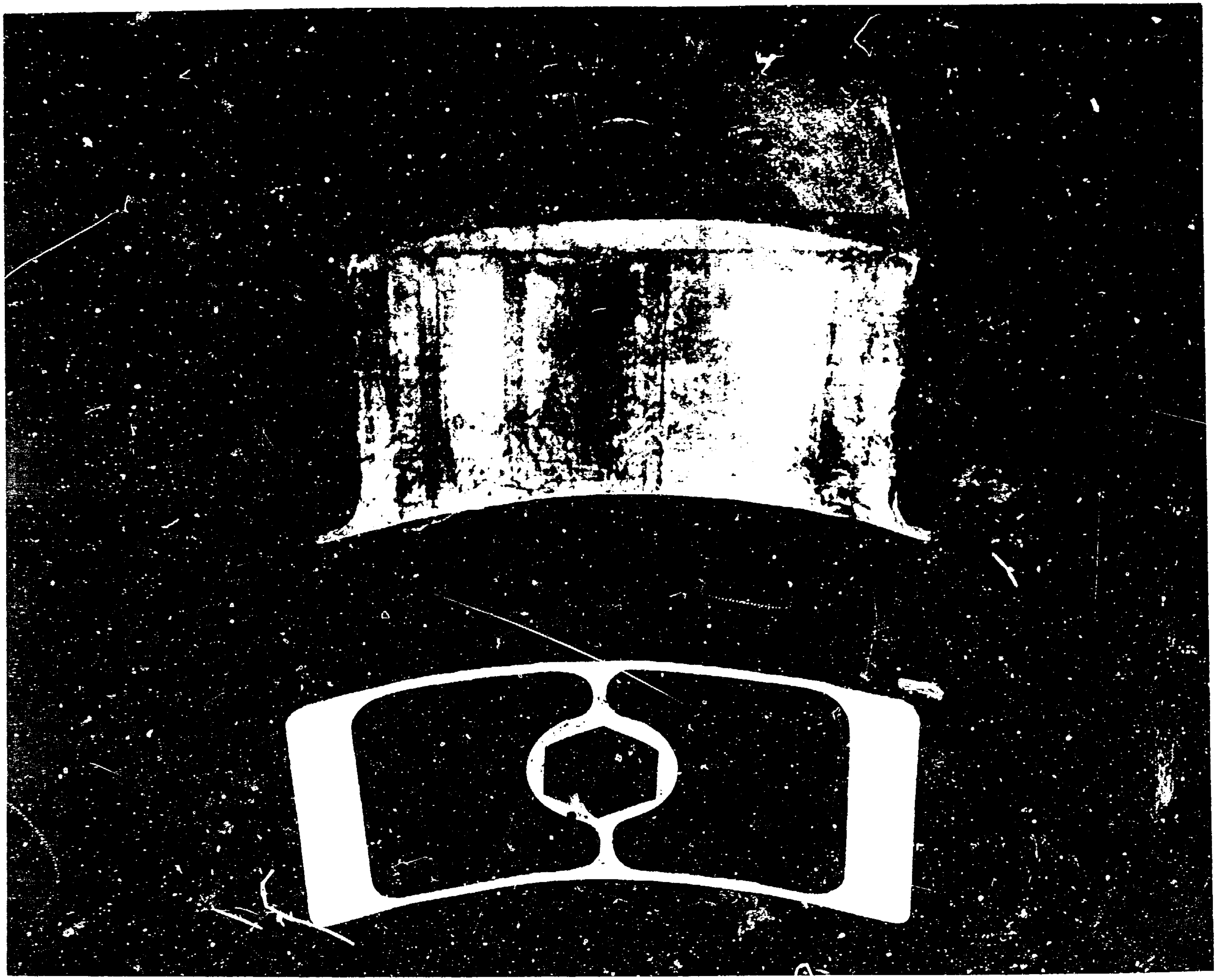


Figure 6. Completed Molars

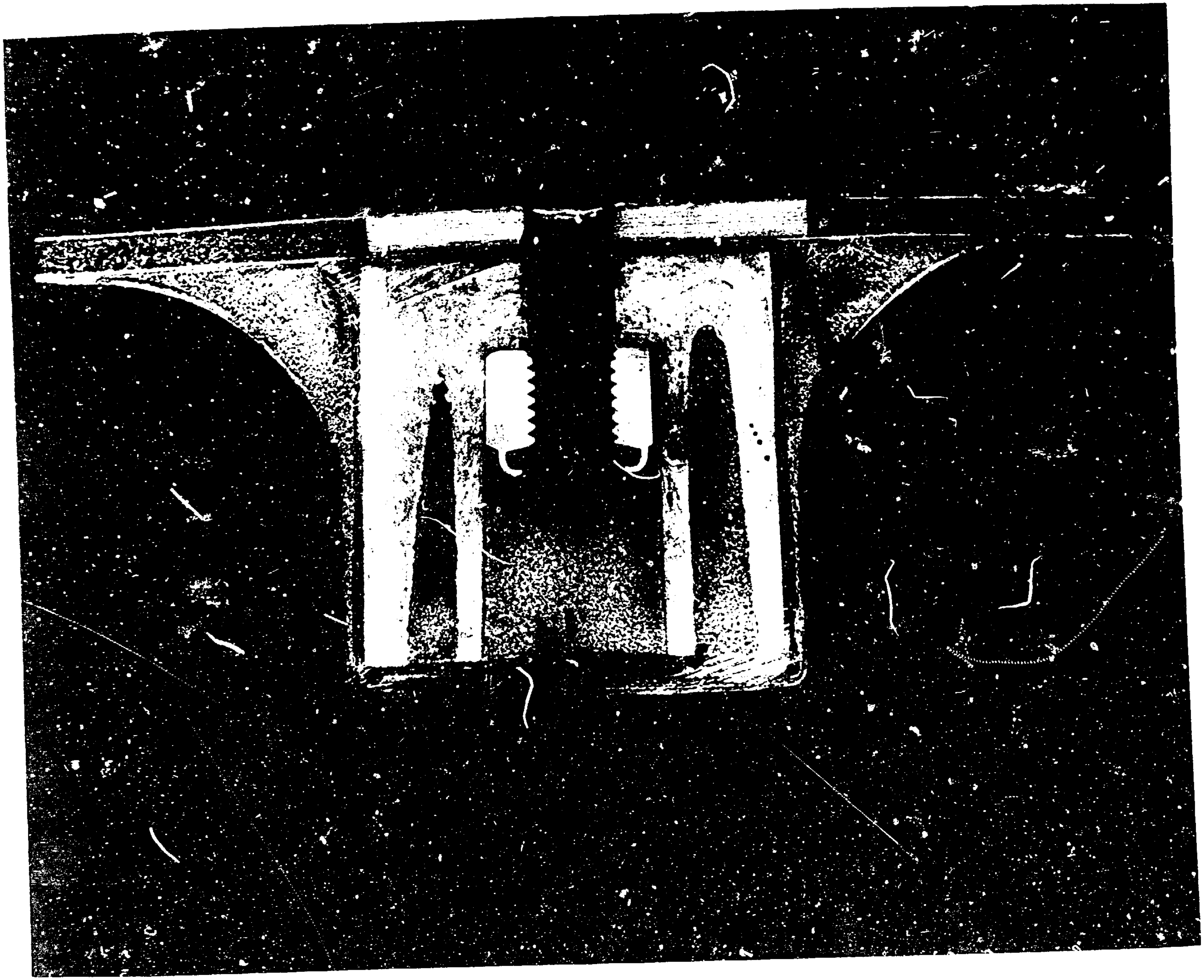


Figure 7. Cross-Sectioned Molar, Showing Inner Construction

Figure 8. Frame Foam Mold and Completed Foam Section

Figure 9. Frame Mold

Figure 10 shows the mold used to form the foam radius in the frames.

Figure 11 shows the completed frame both with and without the foamed-in radius rings.

2) Polar Rings and Caps. The polar rings and caps are compression molded.

Figure 12 shows a completed set of polar rings and caps.

3) Tank Shell. The tank shell consists of the liner (bladder), polar rings, sandwich wall foam core, reinforcement inserts in the foam core and the GRP windings.

a. The ABS plastic liner is thermoformed to the tank configuration.

Figure 13 shows the ABS plastic tube, as received from the tubing extruder, being mounted on the forming support mandrel.

Figure 14 shows the formed liner resting in the forming mold. Note the liner was formed around the two center frames.

b. Mount the formed liner, center frames and polar rings on the winding mandrel.

Figure 15 shows the liner, center frames and polar rings mounted on the winding mandrel. The polar rings are bonded to the outside of the liner.

c. Place the winding mandrel and liner assembly in the winding machine and inflate the liner with air. The liner is now ready for filament windings.

Figure 16 shows the winding mandrel and liner assembly in the winding machine.

d. The filament winding process is as follows: 1) wind one hoop ply of glass; 2) wind one helical layer of glass; 3) wind one hoop ply of glass; 4) position the preformed foam over the wet

Figure 10. Foam Radi Molds

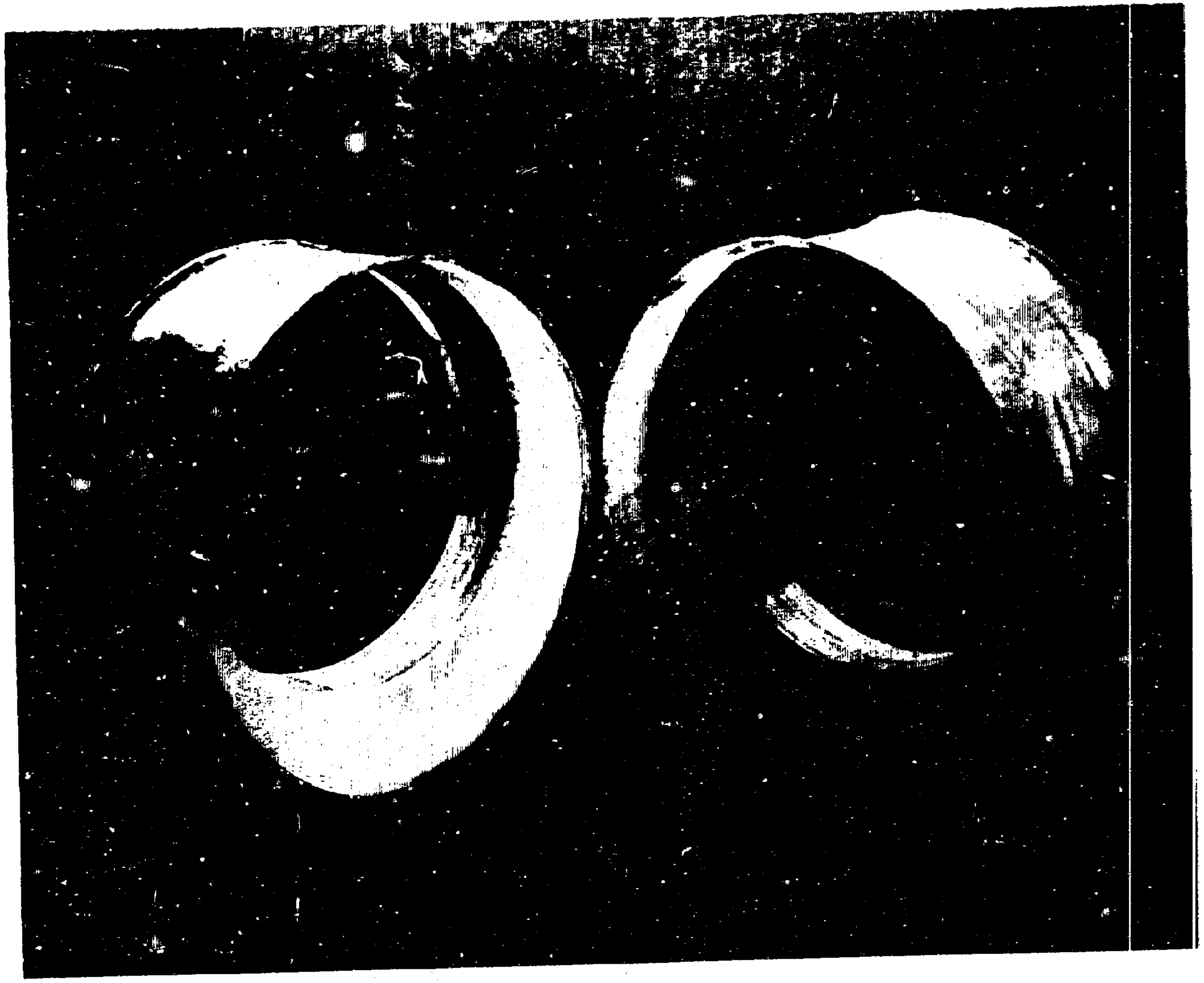


Figure 11. Completed Frames Both With and Without Foamed-In Radius Rings

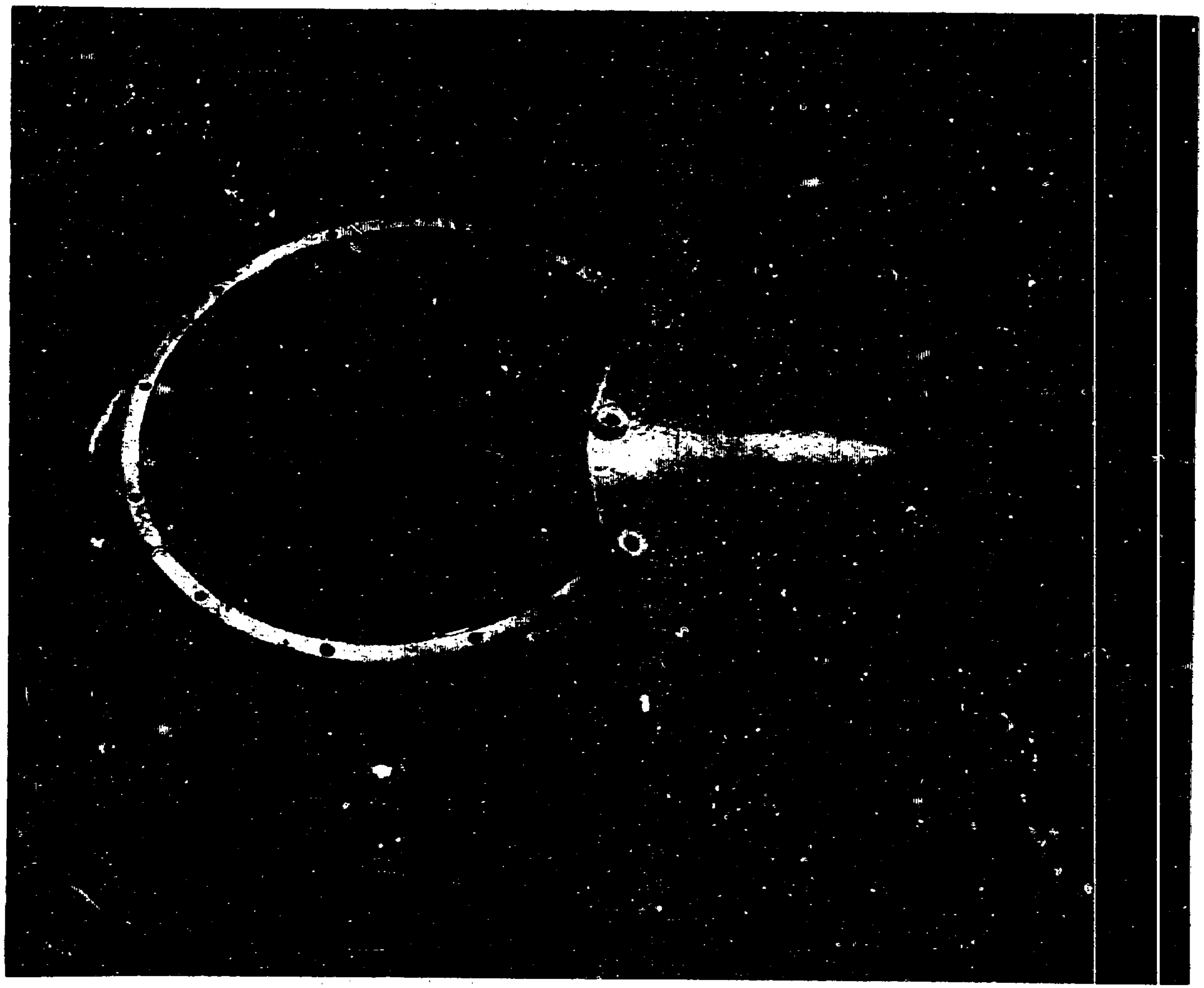


Figure 12. Polar Ring and Cap

Figure 13. ABS Plastic Tube

Figure 14. Formed Liner Resting in Forming Mold

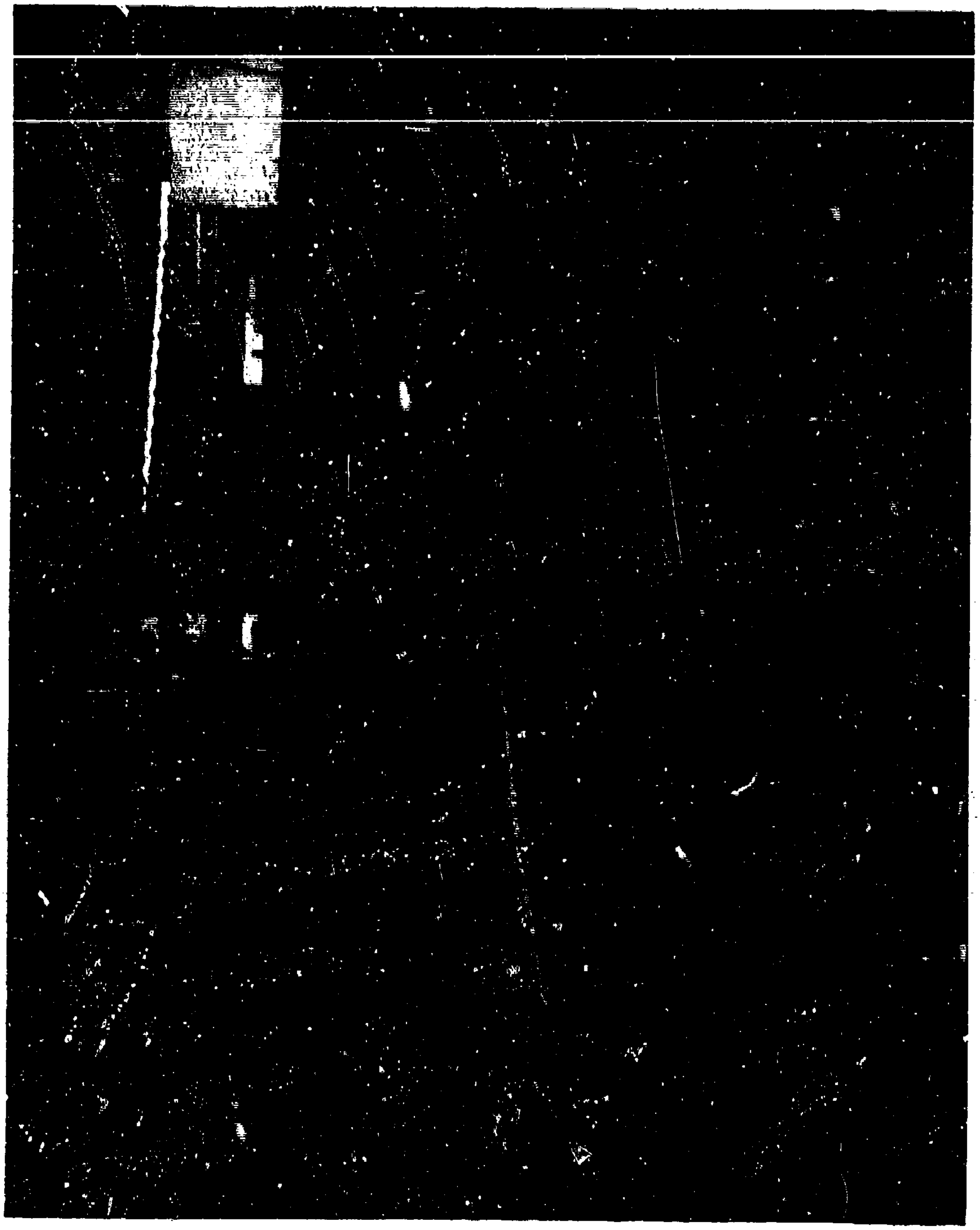


Figure 15. Liner - Winding Mandrel Assembly

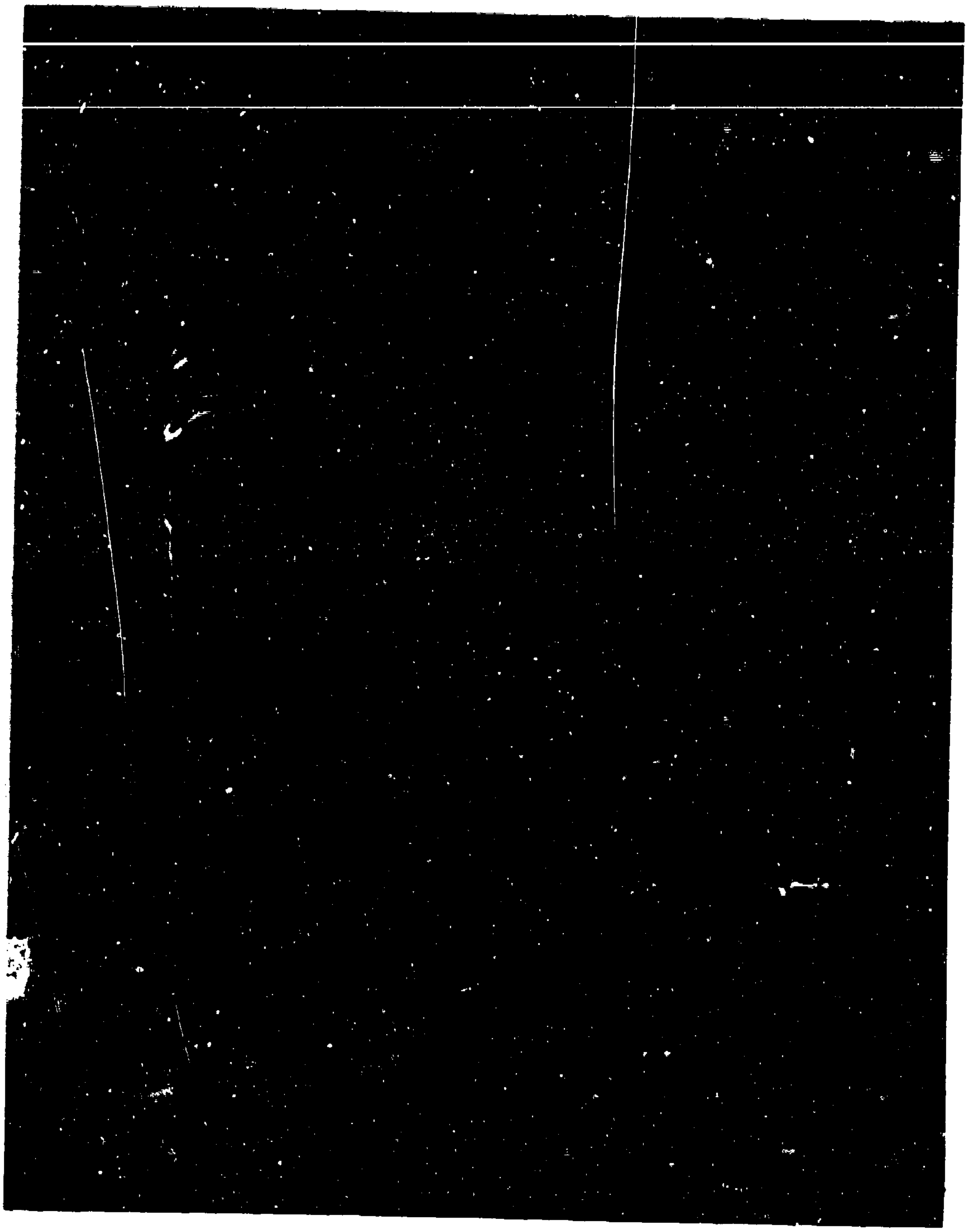


Figure 16. Winding Mandrel Assembly in Machine

windings; 5) install GRP reinforcing pads in the proper locations by cutting sections out of the foam; 6) wind one or two hoop plies of glass; 7) wind one helical layer of glass; 8) wind one or two hoop plies of glass.

Figure 17 shows the winding of the first hoop ply of glass.

Figure 18 shows the winding of the first helical layer.

Figure 19 shows the foam being removed from its forming mold.

Figure 20 shows the complete set of formed foam sections.

Figure 21 shows the foam being positioned against the wet helical layer.

Figure 22 shows the GRP reinforcing laminates which will replace section of the foam.

Figure 23 shows the GRP reinforcing laminates positioned in the foam.

Figure 24 shows the winding of the third hoop ply of glass.

Figure 25 shows the winding of the second helical layer of glass.

Figure 26 shows the winding of the fourth hoop ply of glass.

e. The tank is placed under heat lamps and the excess resin wiped off as the resin gells.

f. The tank is cured using heat lamps.

g. The winding mandrel is removed and the internal plumbing, fitting, and the rings to which the nose fairing and tail fins are attached.

Figure 27 shows a tank before the fittings and internal plumbing are attached.

Figure 28 shows the internal hardware and fittings.

Figure 29 shows a view looking aft inside the tank.

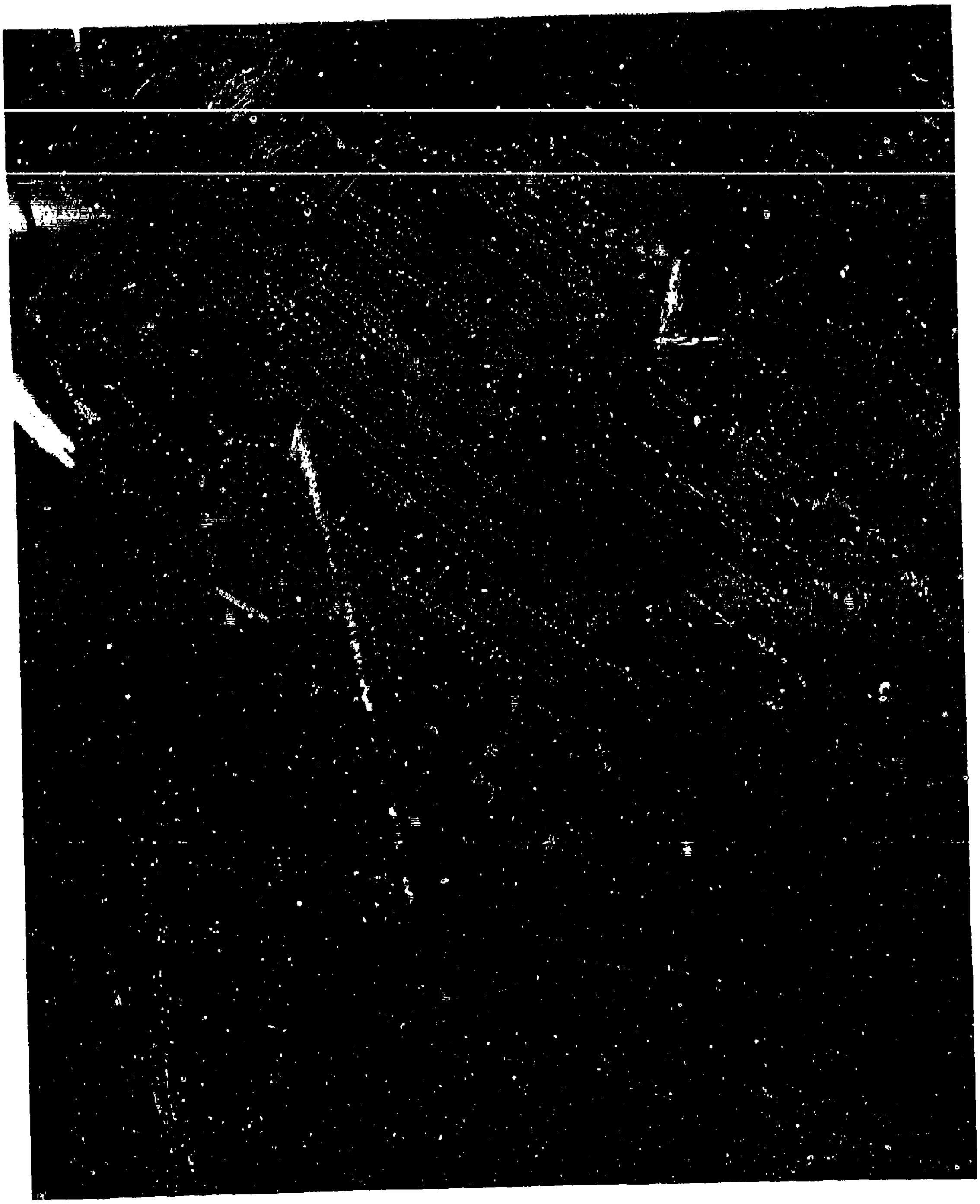


Figure 17. Winding of First Hoop Ply

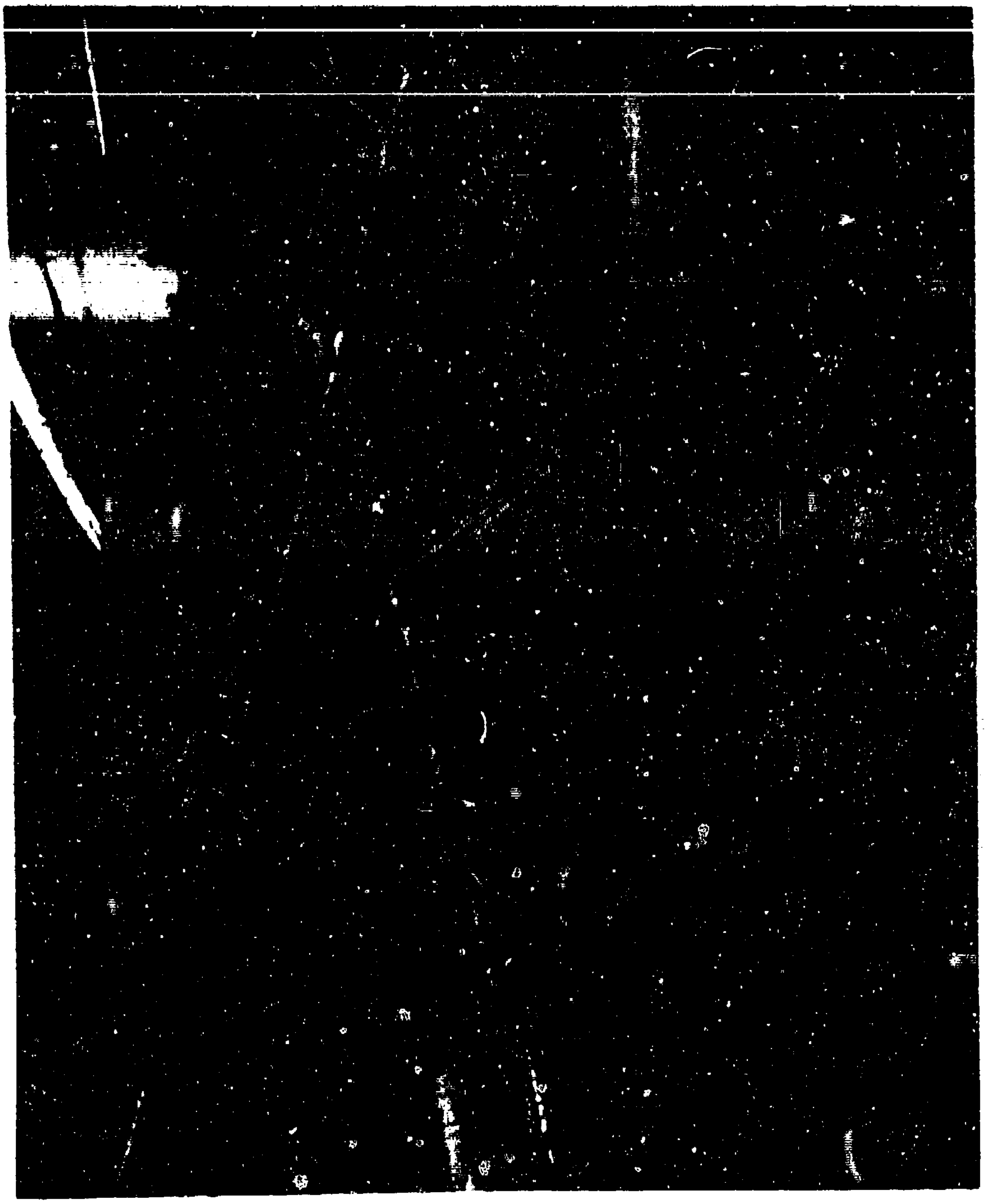


Figure 18. Winding of First Helical Layer

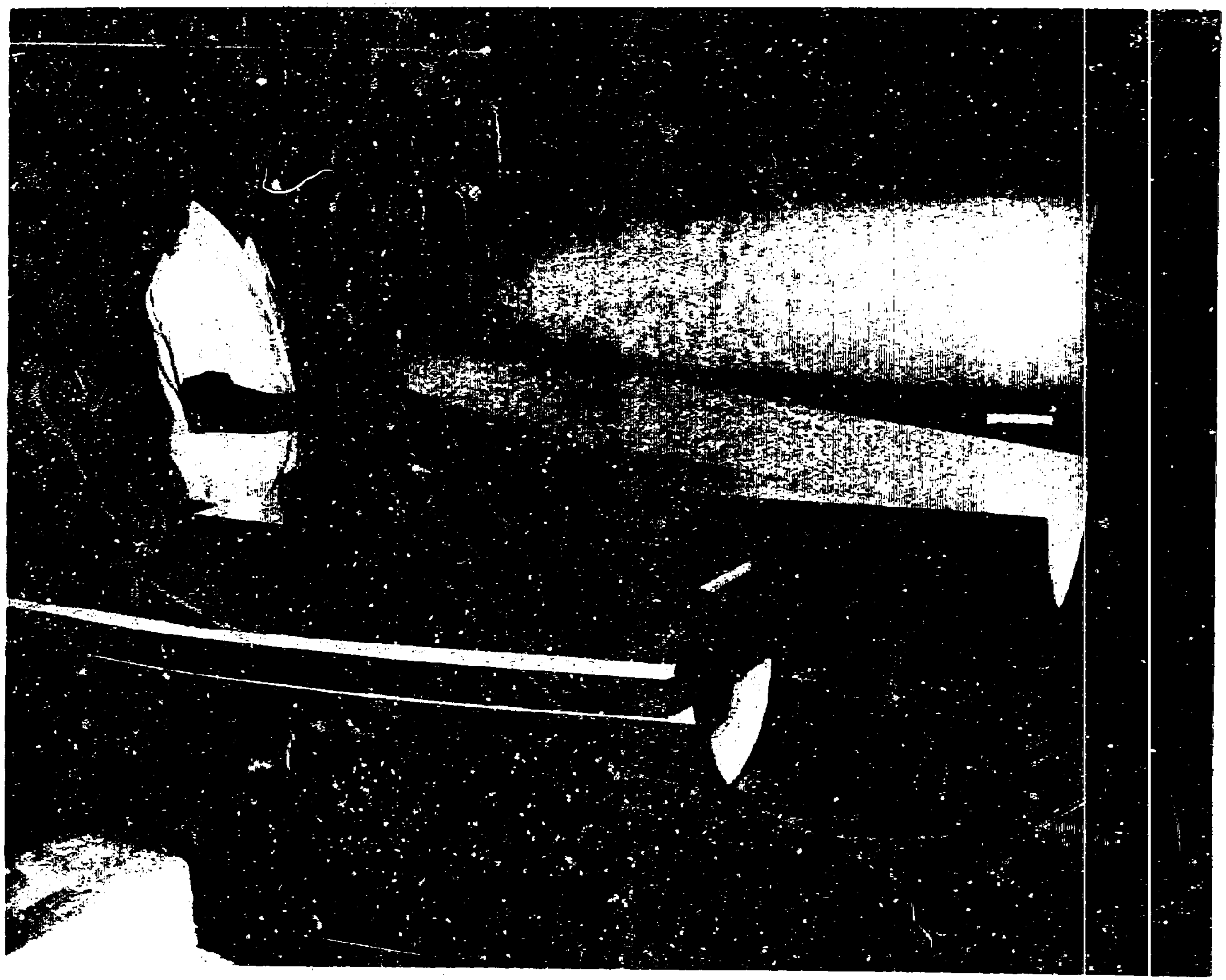


Figure 19. Foam Being Removed from Forming Mold

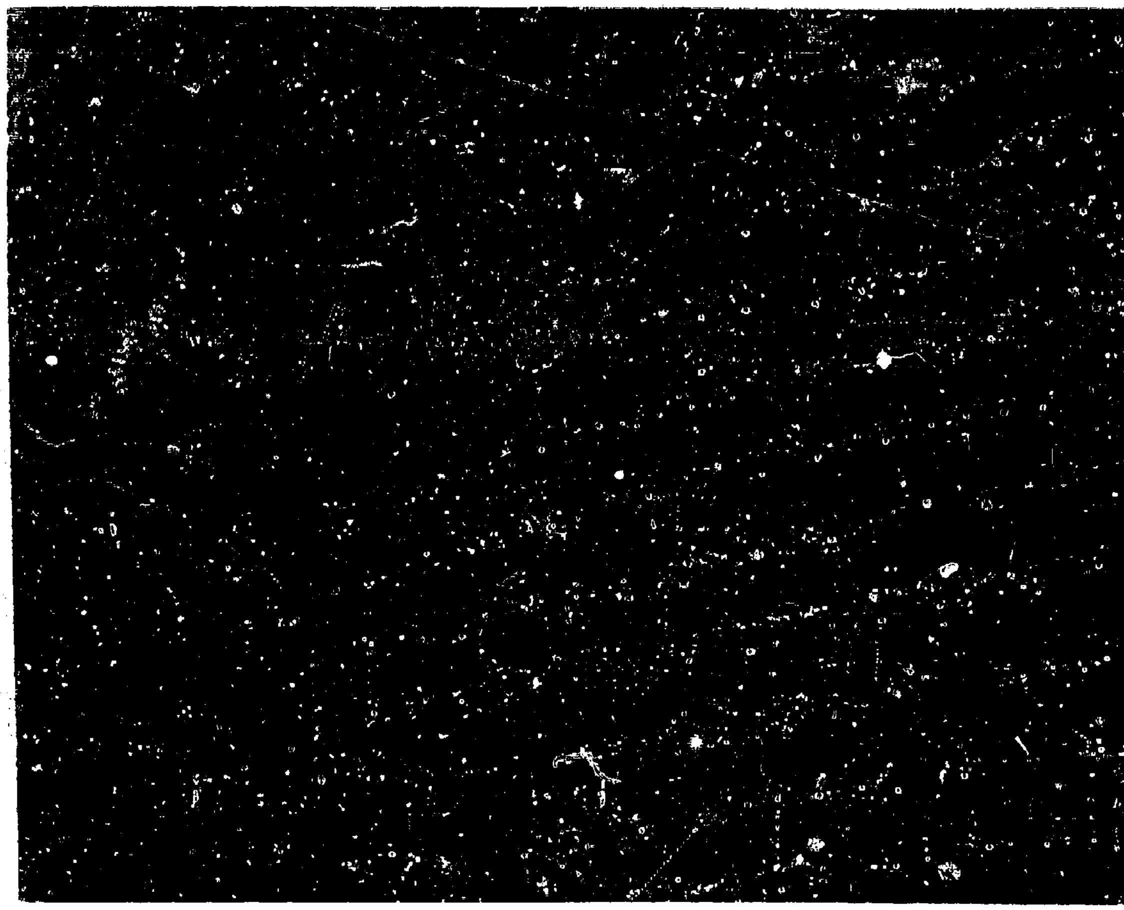


Figure 20. Set of Foam Sections

Figure 21. Foam Being Positioned Against Windings

Figure 22. GRP Reinforcing Laminates

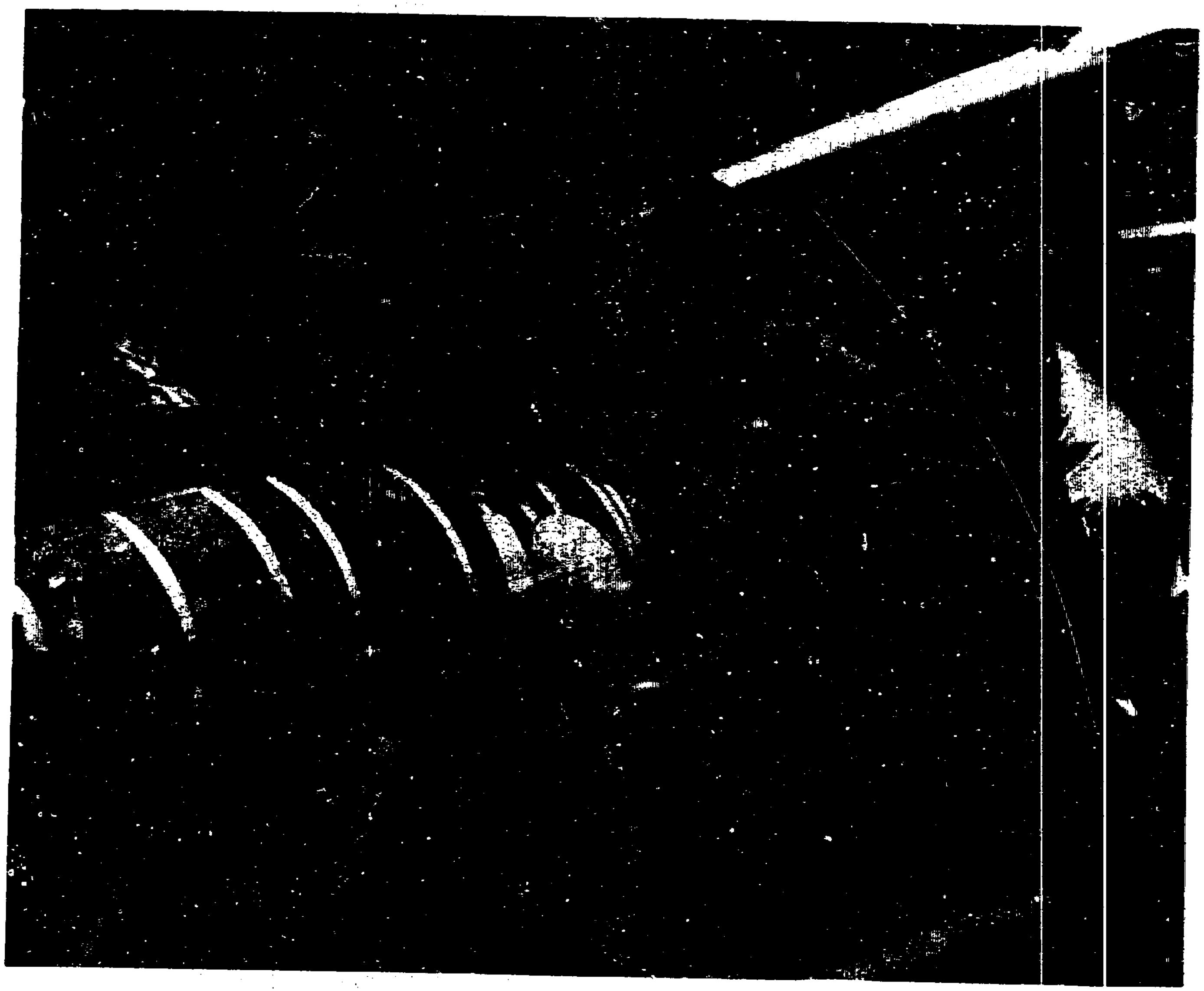


Figure 23. GRP Reinforcing Laminates in Place

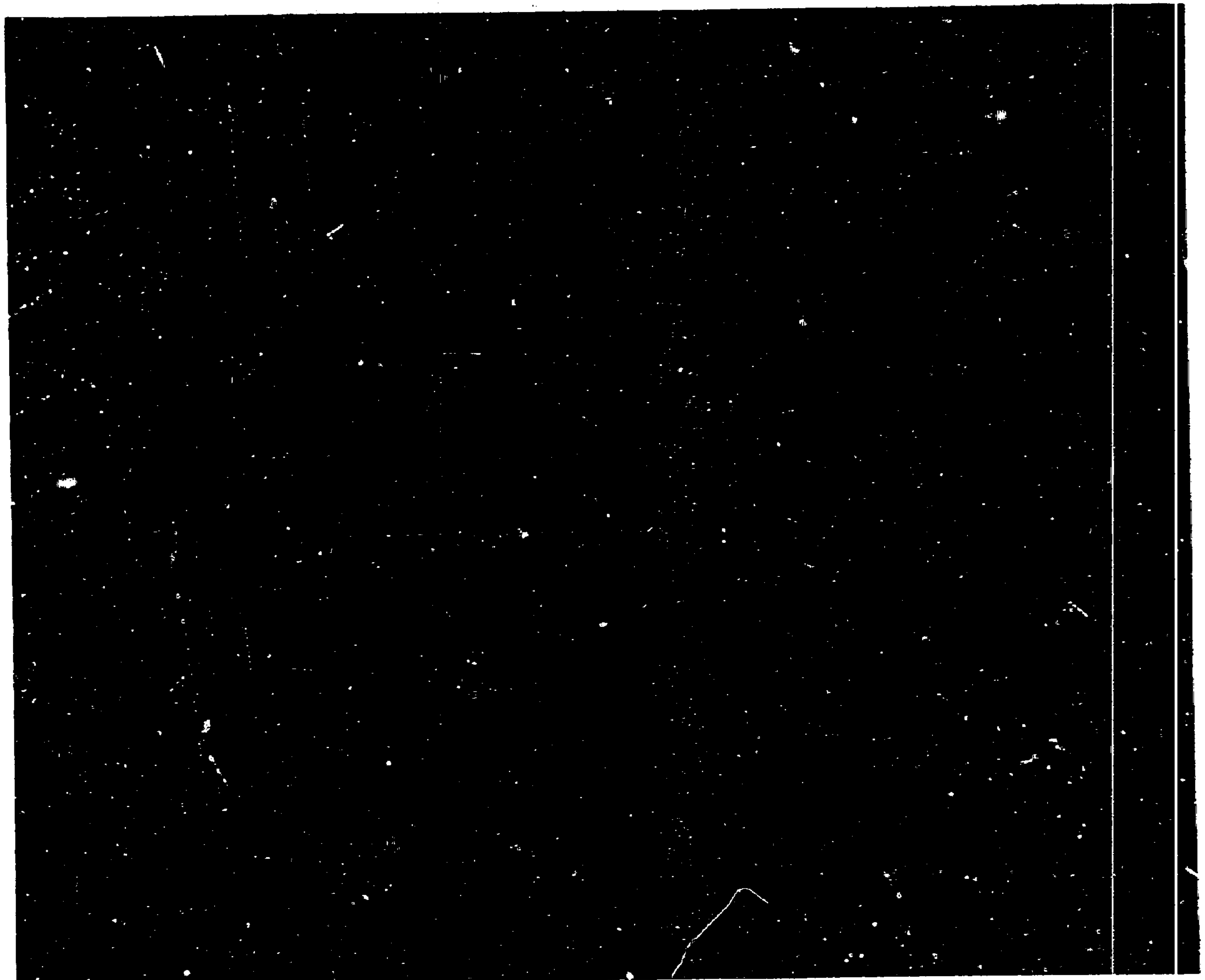


Figure 24. Winding of Third Hoop Ply

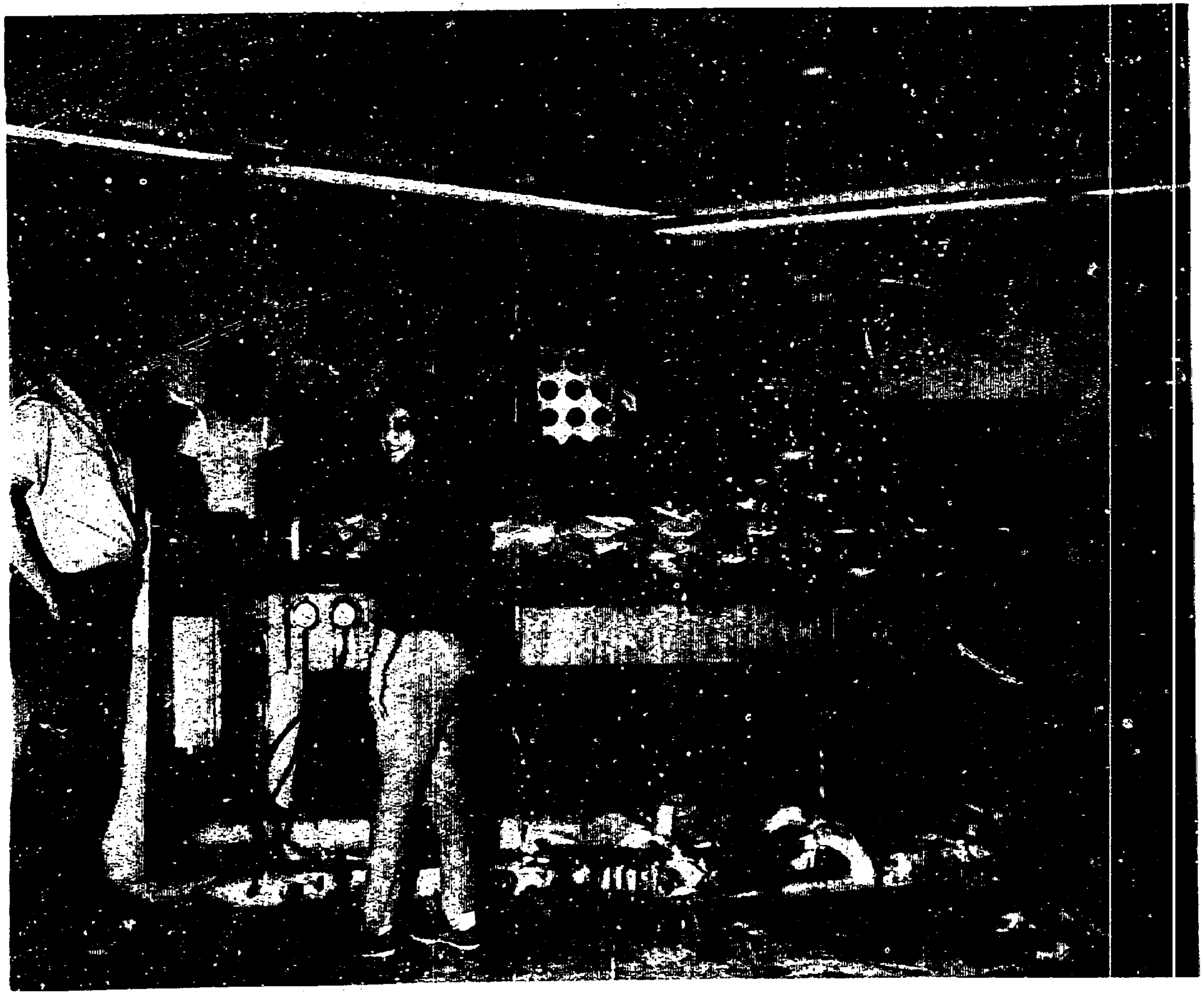


Figure 25. Winding of Second Helical Layer

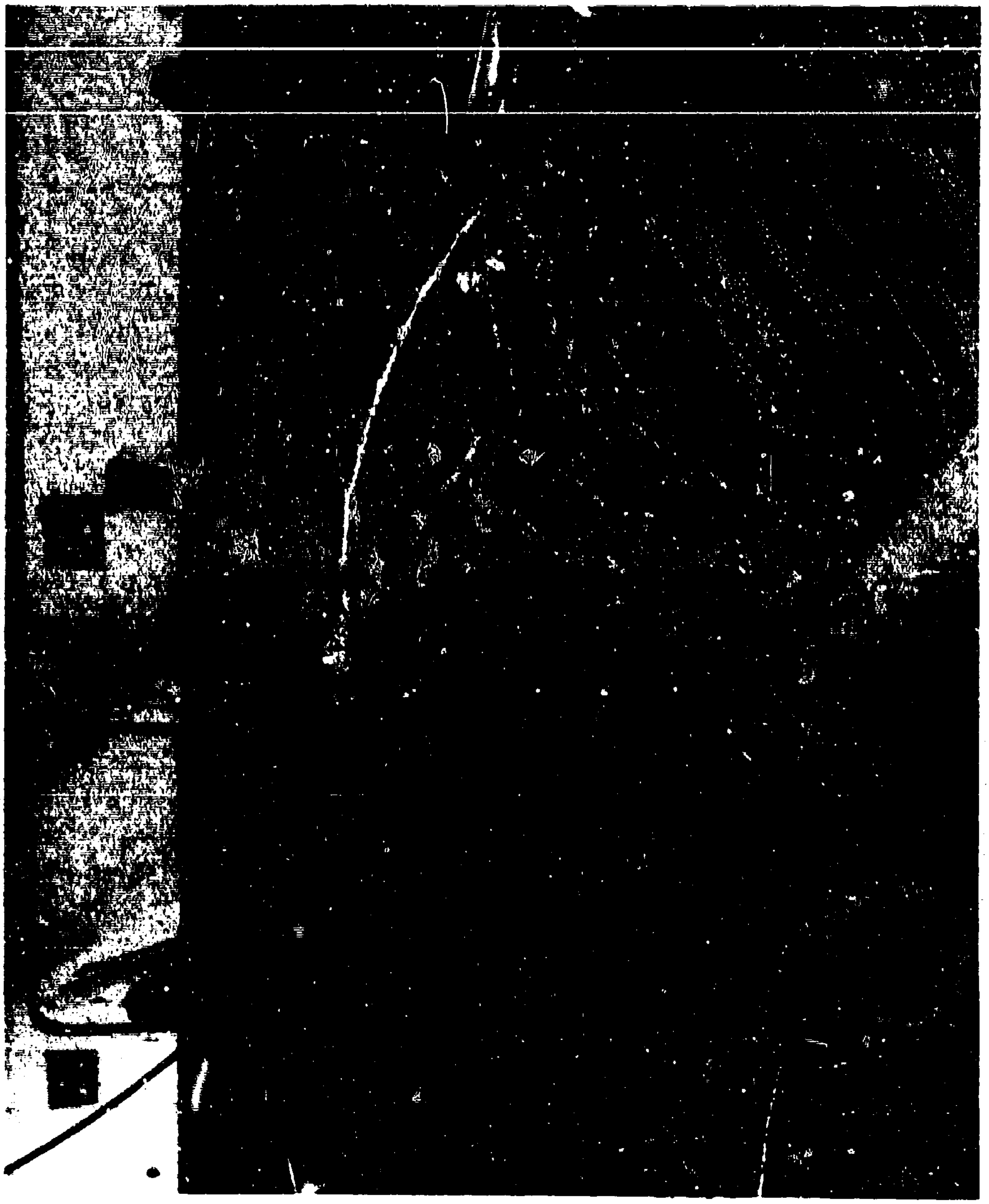


Figure 26. Winding of Fourth Hoop Ply

Figure 27. Tank Prior to Having Plumbing and Internal Hardware Attached

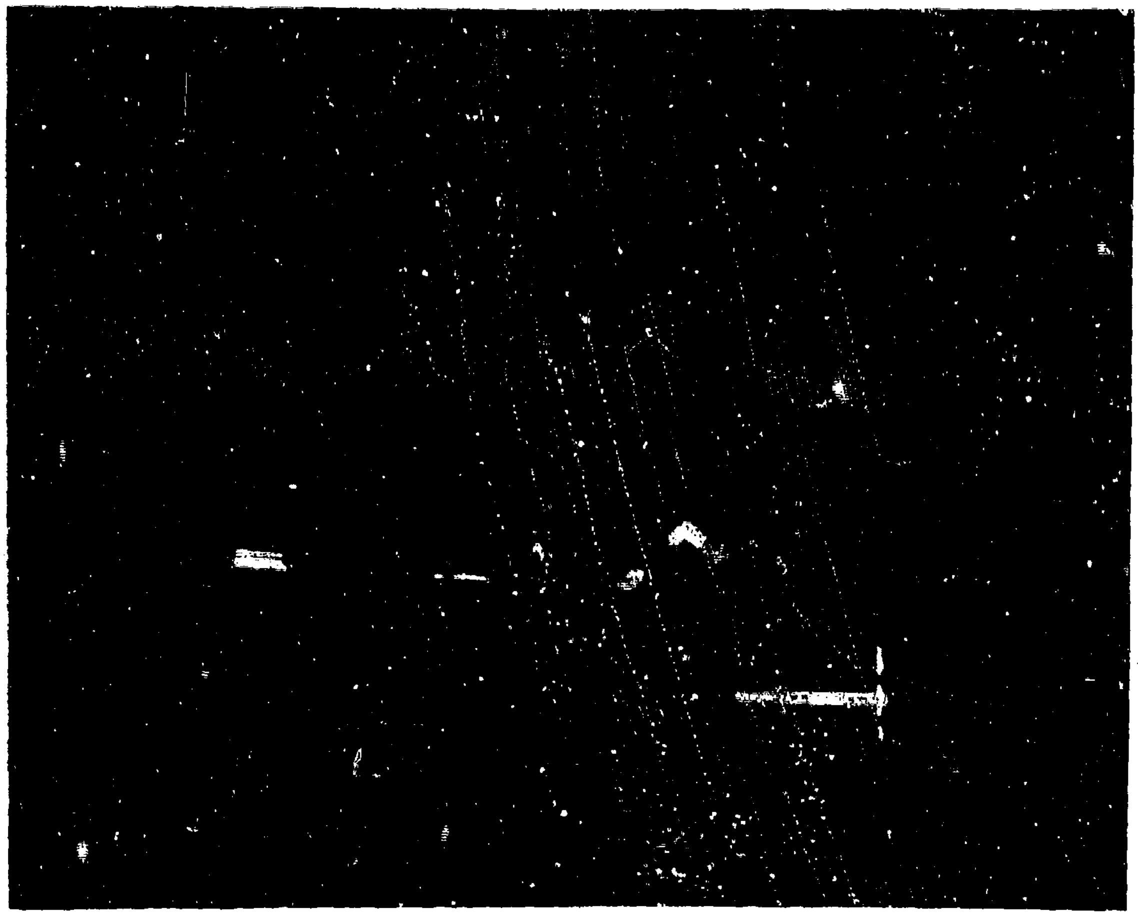


Figure 28. Internal Hardware and Fittings

Figure 29. View Looking Aft Inside the Tank

Figure 30 shows a view looking forward inside the tank.

4) Tail Fins. The tail fins are a one-piece, sandwich-wall assembly having GRP faces and a urethane foam core.

a. Laminate the GRP skins using three female molds for the outside skin and a male mold for the inside skin.

Figure 31 shows the tail fin laminating and assembly molds.

b. Bond the outside skins together using their molds as a holding fixture with one ply of 181 fabric wrapped over .128" diameter fiber glass cordage with room temperature curing epoxy.

c. Bond premolded sections of high density foam in the fin root areas.

Figure 32 shows a premolded high density foam section.

d. Bond the inside skin to the high density foam section and in the region where the outer and inner skins join together.

Figure 33 shows the high density foam sections installed between the GRP skins.

e. Foam-in-place the area between the outer and inner skins.

f. Trim and drill the attachment holes in the tail fin assembly.

Figure 34 shows the completed tail fin assembly.

5) Nose Cap. The nose cap is a thermoformed plastic shell which is reinforced with a GRP laminate.

a. Thermoform the outside shell from ABS plastic.

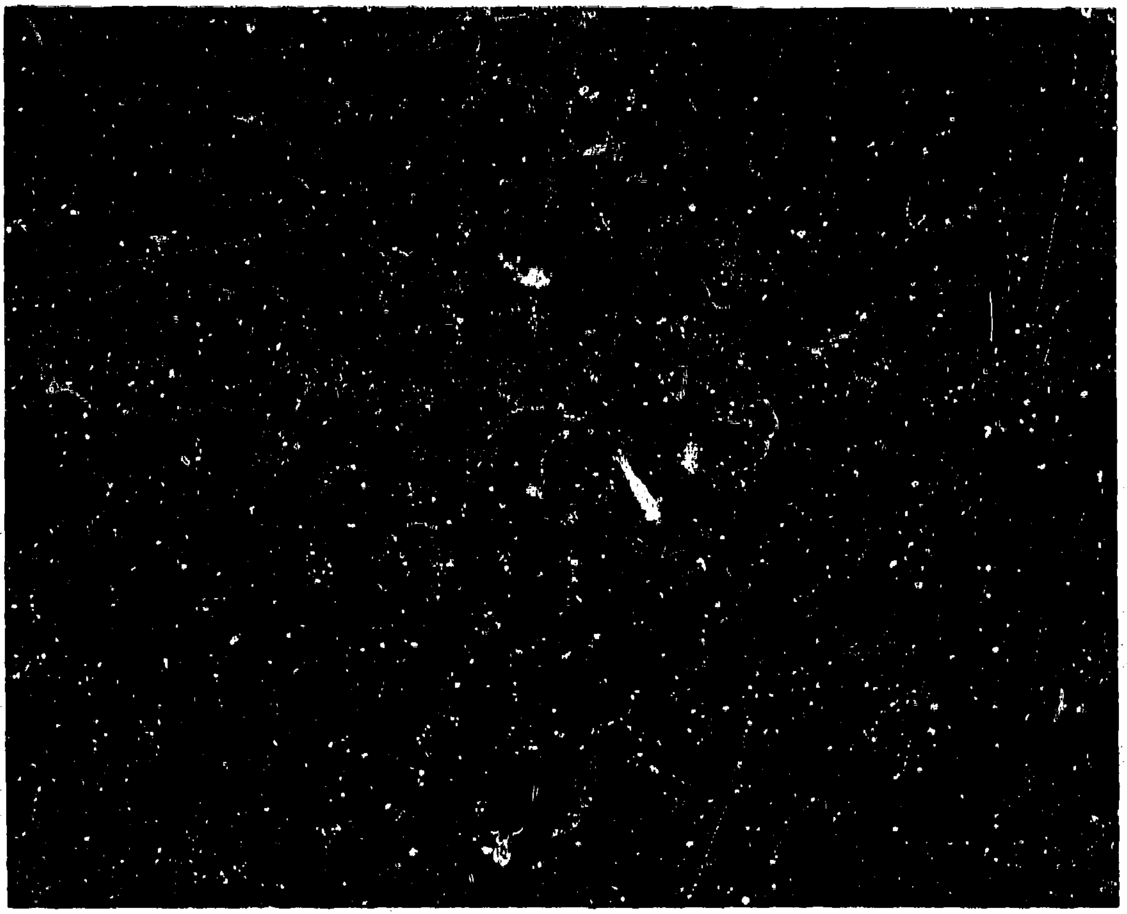


Figure 30. View Looking Forward Inside the Tank

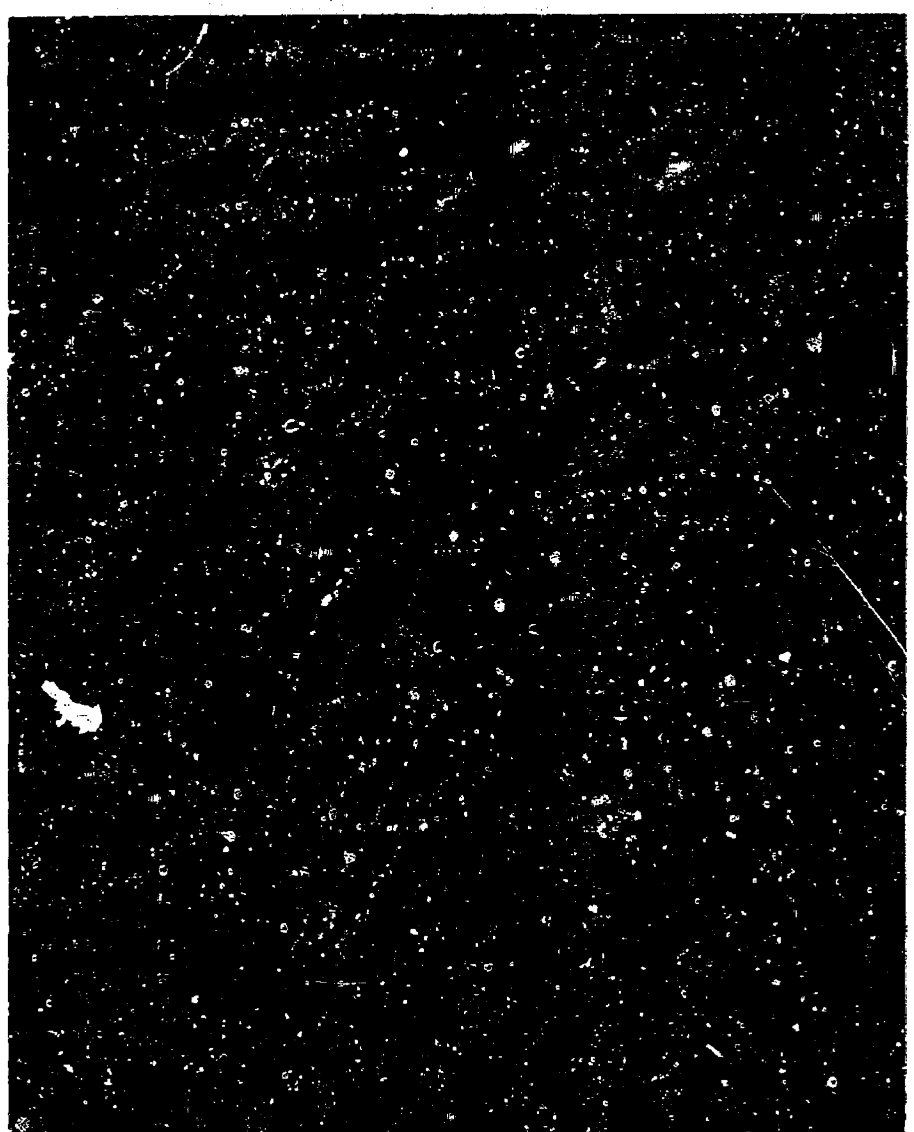


Figure 31. Tail Fin Laminating and Assembly Molds

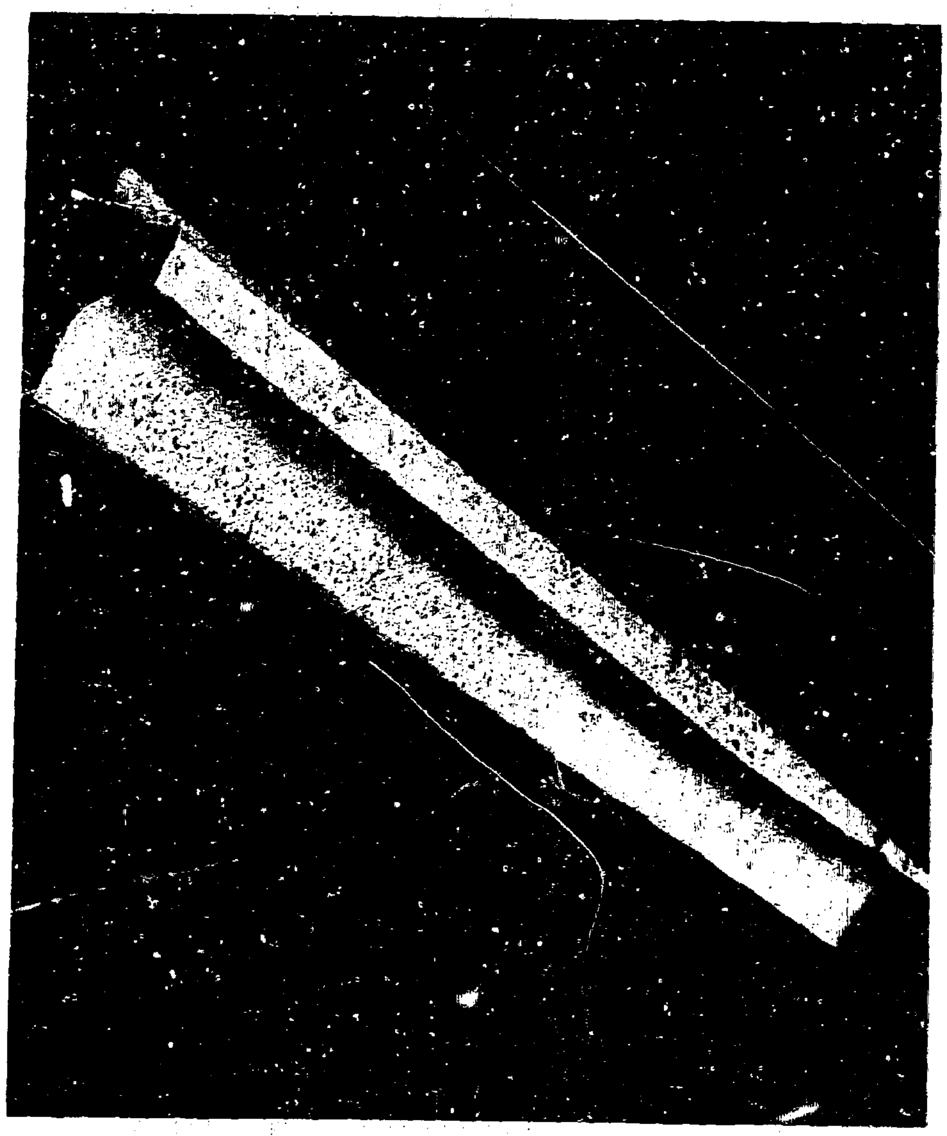


Figure 32. Premolded Foam Sections for Tail Fins

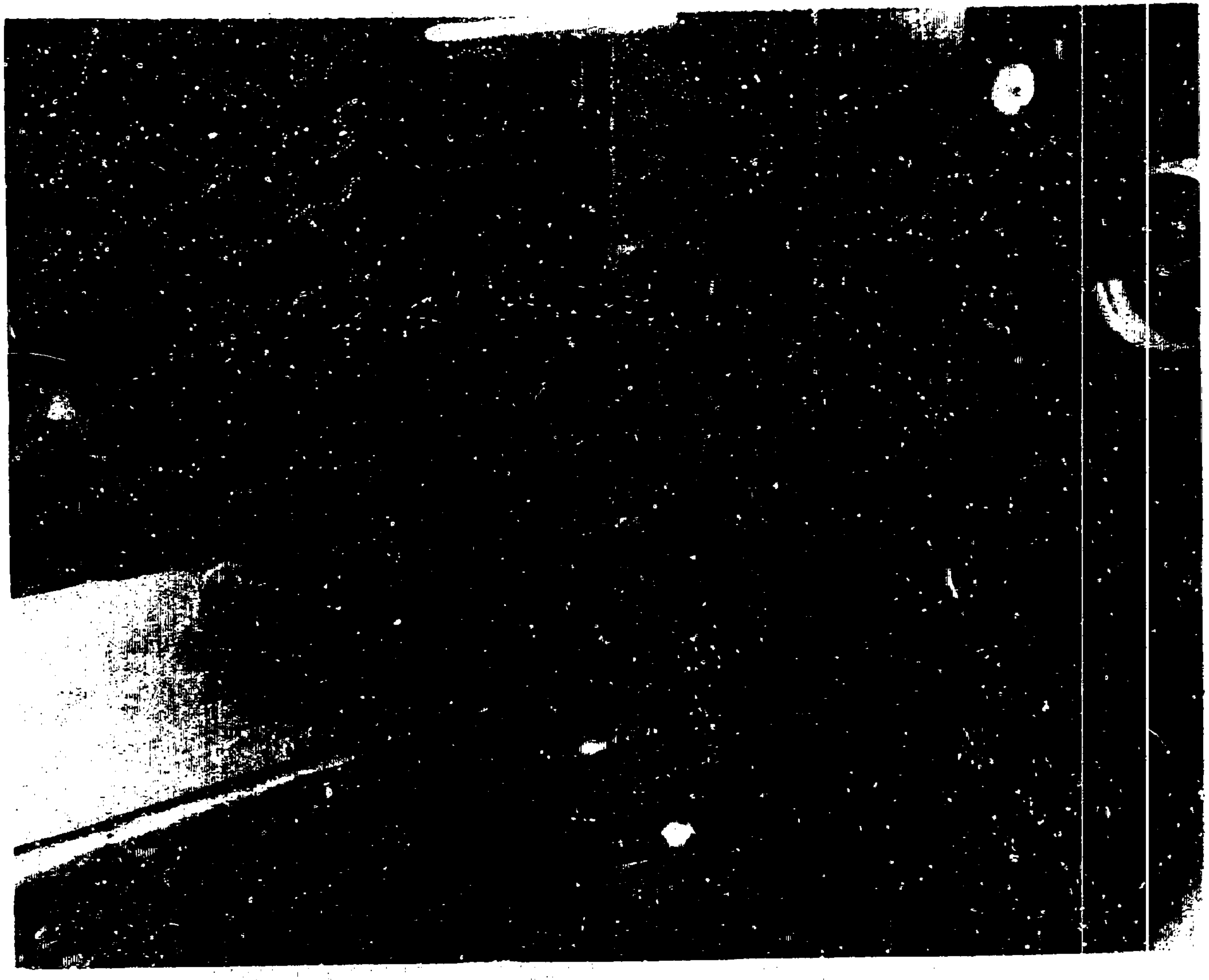


Figure 33. Premolded Foam Sections Installed Between the GRP Skins

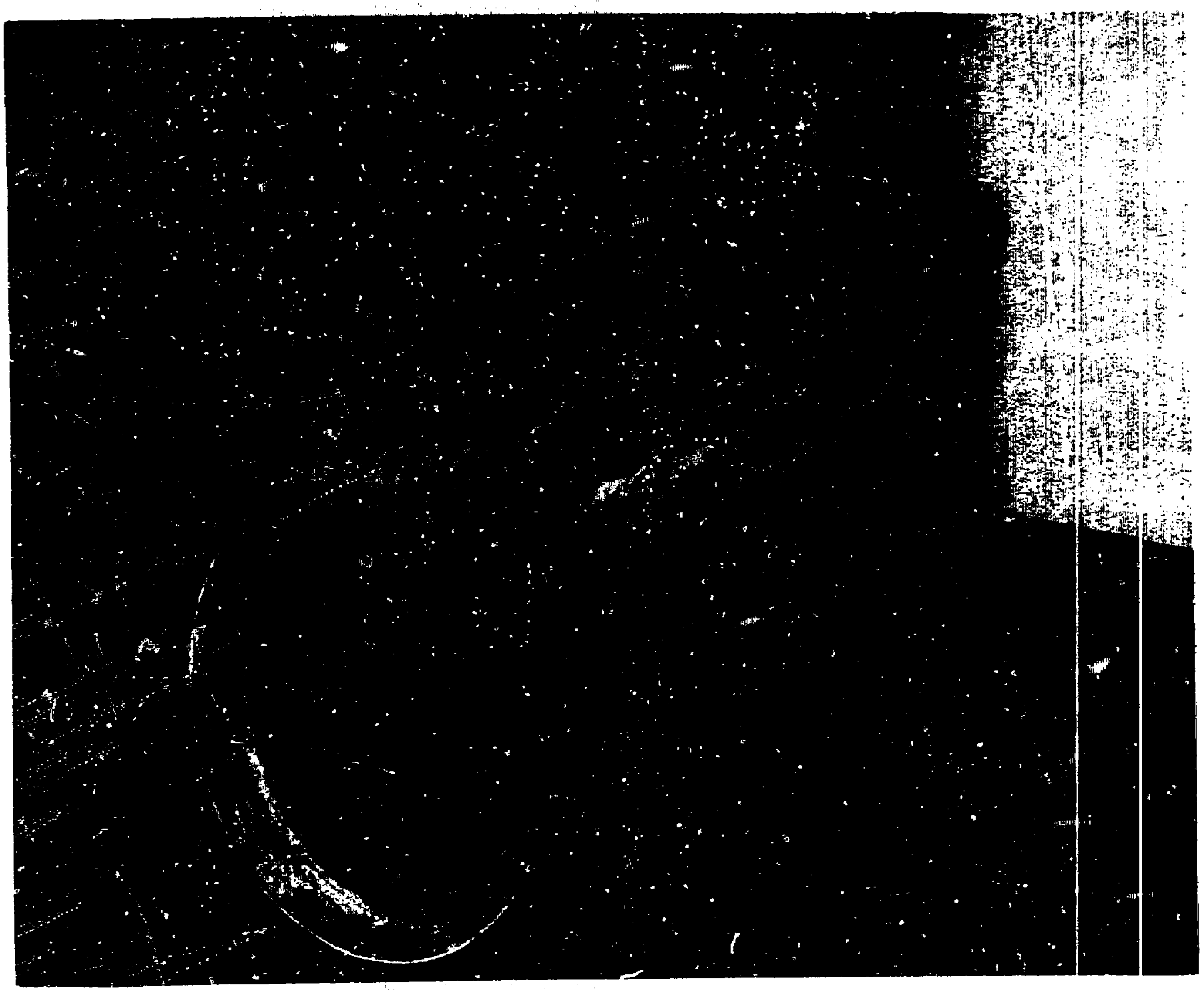


Figure 34. Complete Tail Fin Assembly

b. Layup three plies of 181 fabric/epoxy on the inside surface of the thermoformed shell.

c. Trim excess material and drill attachment holes.

Figure 35 shows the completed nose fairing.

6) Mounting Rings. The mounting rings are made from high density foam with the nose and tail attachment inserts molded in place. These rings bond directly to the tank shell.

Figure 36 shows the mounting ring mold.
Figure 37 shows a completed mounting ring.

Table IX summarizes the materials and winding sequence used in the fabrication of the tank shells.

Figure 35. Completed Nose Fairing

Figure 36. Ring Mold (Tail Fin and Nose Fairing Attachment)

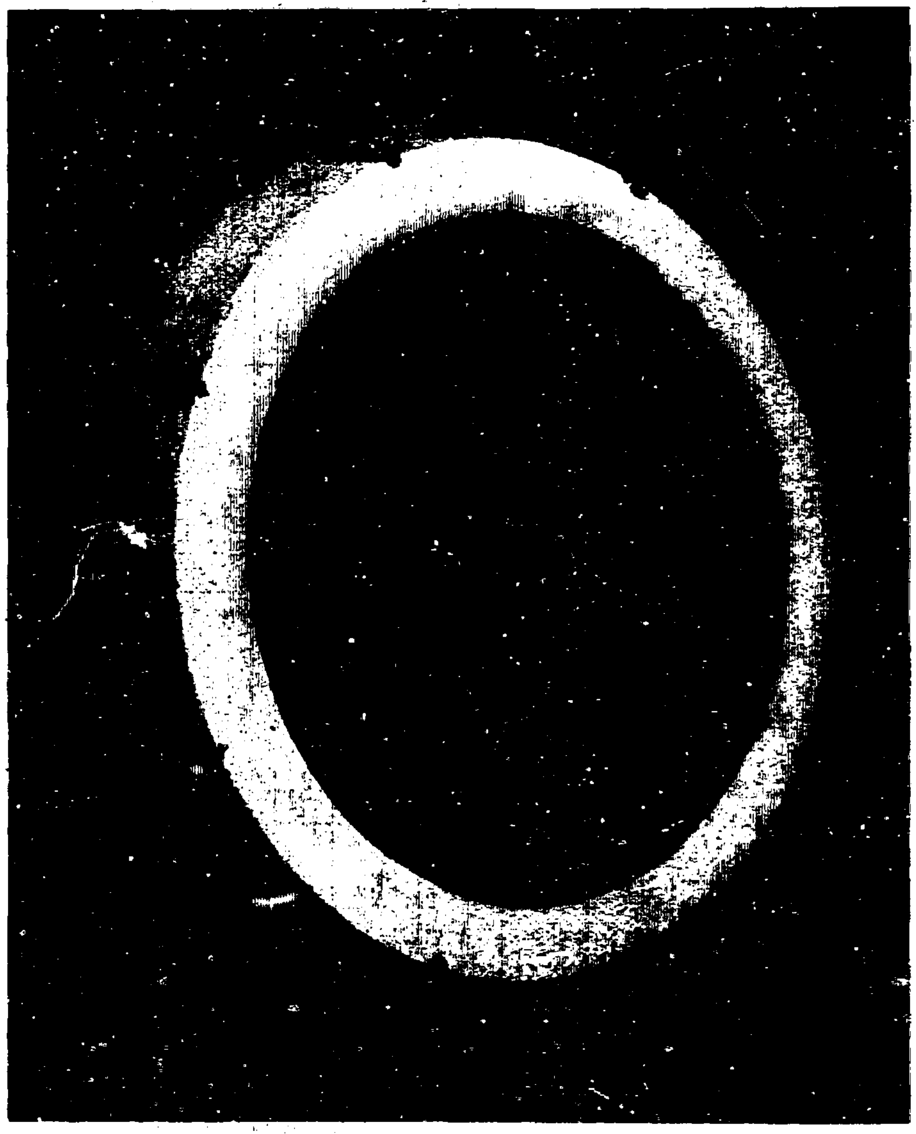


Figure 37. Completed Ring (Tail Fin and Nose Fairing Attachment)

TABLE IX

TANK SHELL FABRICATION SUMMARY

TANK S/N	RESIN SYSTEM*	FOAM TYPE	GLASS TYPE	WINDING PATTERN
001	FSCS 102	PVC Johns-Manville	Aero Rove 3 Single End	Single Circuit 1C-1H-1C-F-1C-1H-1C
002	FSCS 106	"	"	"
003	FSCS 102	"	"	12 Circuit 1C-1H-1C-F-1C-1H-1C
004	FSCS 102	"	"	"
005	FSCS 102	"	"	12 Circuit 1C-1H-2C-F-1C-1H-2C
006	FSCS 106	PVC B. F. Goodrich	"	"
007	FSCS 106	"	"	"
008	FSCS 106	"	S Glass 9 End Rovings	12 Circuit 1C-1H-1C-F-1C-1H-1C
009	FSCS 106	"	"	"
010	FSCS 106	"	"	"

* See Appendix III.

SECTION VI

INSTRUMENTATION AND TEST SETUP

The test was set up in accordance with reference 7, "Test Procedure QTPA-100 for the Cessna A-37B Aircraft One Hundred Gallon External Fuel Tank."

The tanks were internally and externally pressurized using the shop air and vacuum systems. The flight structural loads were applied manually using turnbuckles with Dillon dynamometers to measure the applied force.

Figure 38 shows the external pressure test setup.

Figure 39 shows the test stand with a tank in position ready for structural testing.

Figure 40 shows the test setup used to measure the weight and center of gravity.

Figures 41 and 42 show the tank with the tail fin loads applied.

Figure 43 shows the tank with the flight loads applied.

Figure 44 shows a close-up of the sway brace attachment.

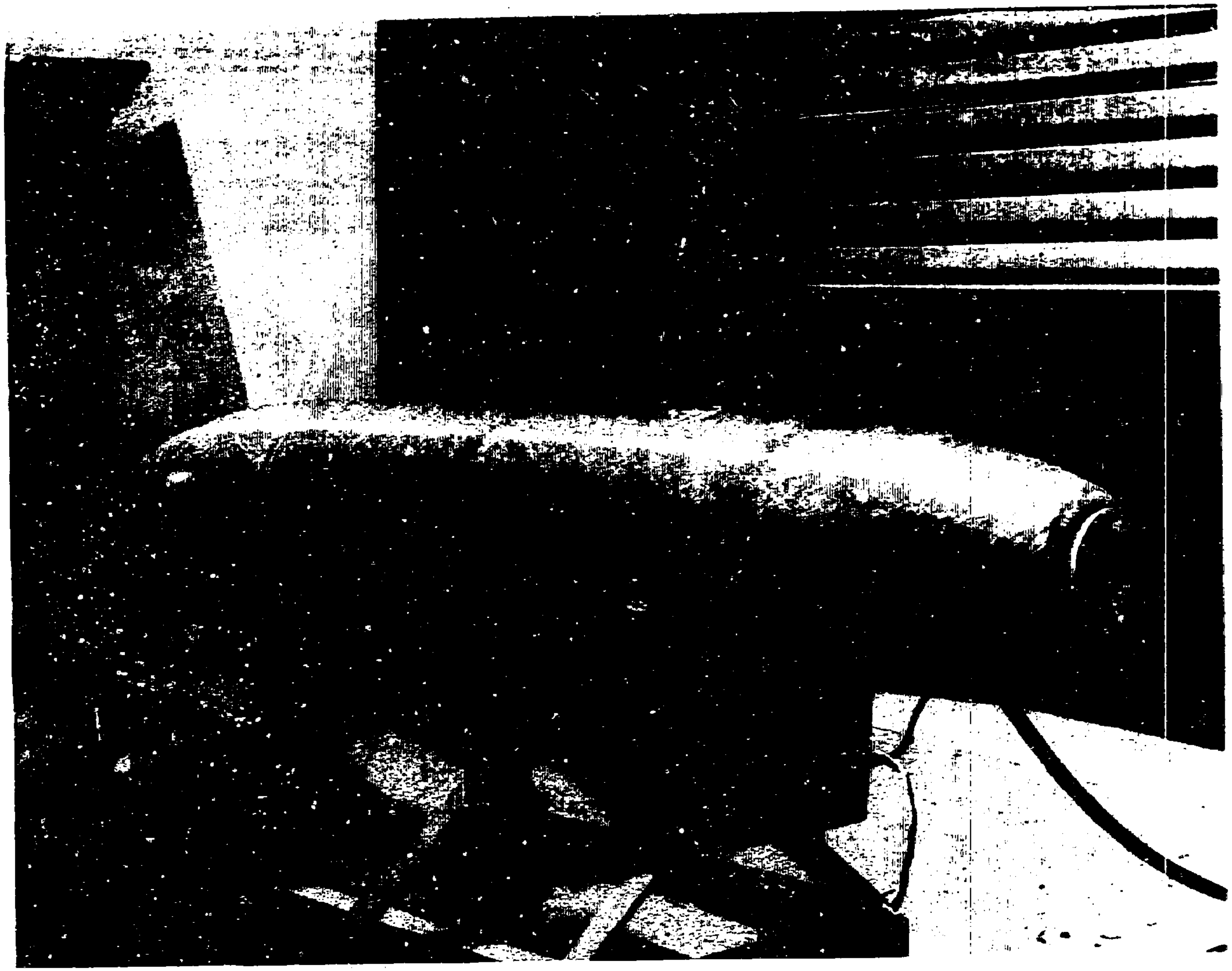


Figure 38. External Pressure Test Setup

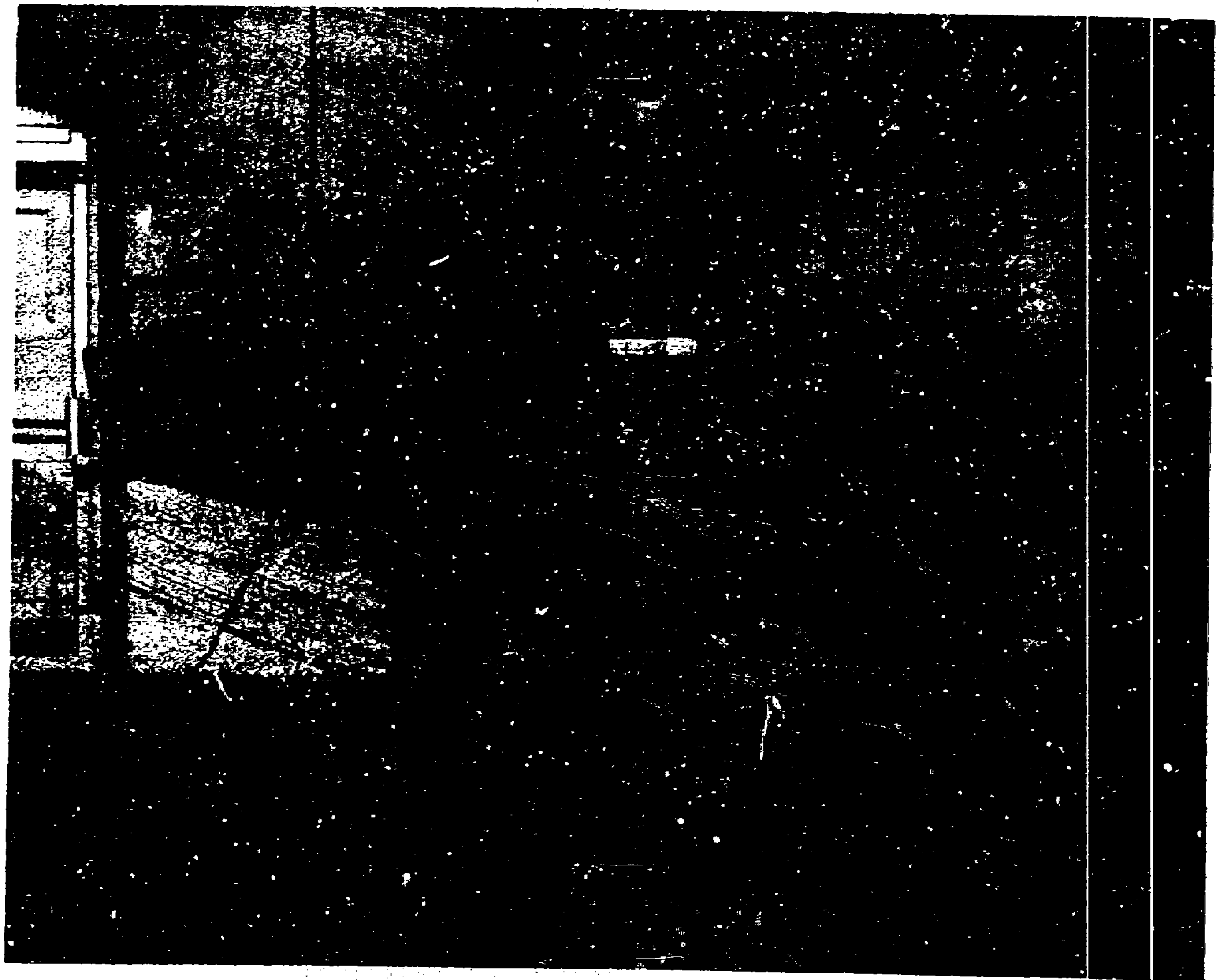


Figure 39. Test Stand with Tank in Position for Testing

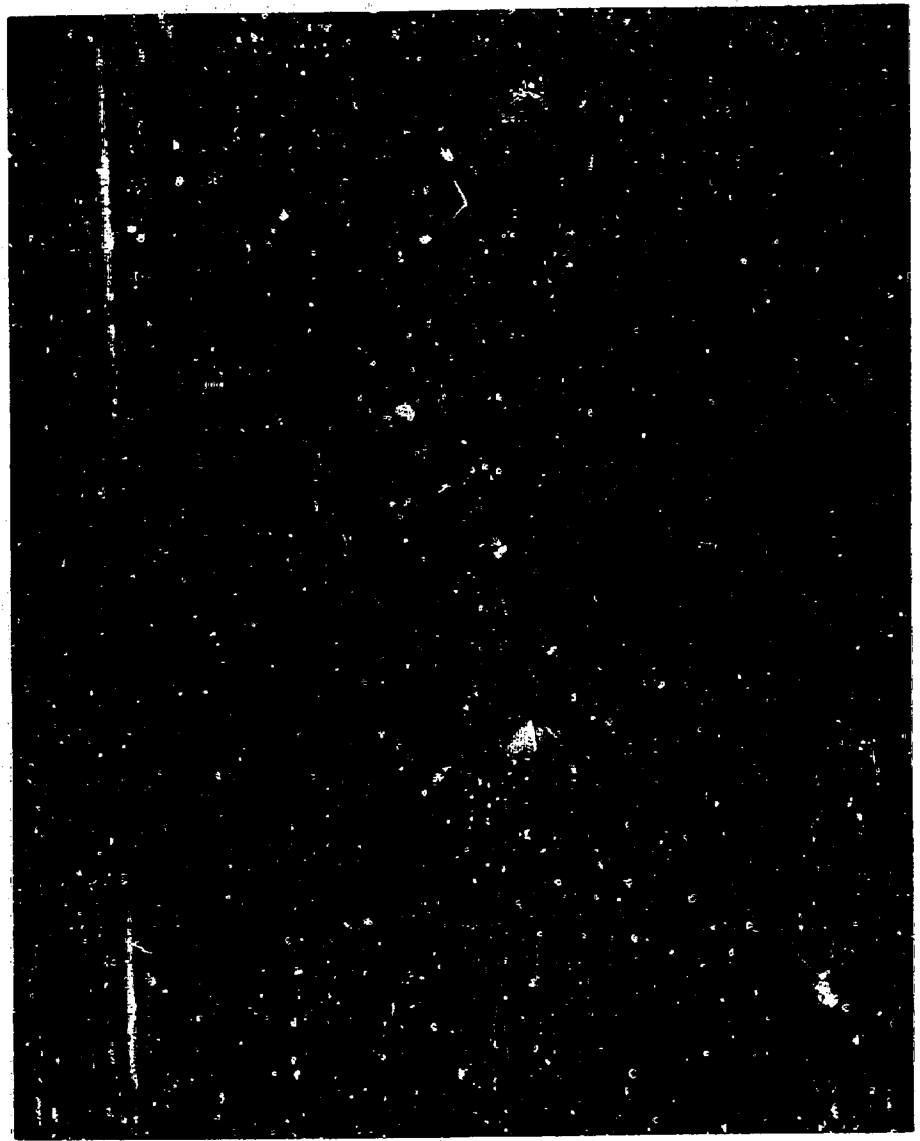


Figure 40. Test Setup for Measuring Weight and Center of Gravity

Figure 41. Test Setup for Tail Fin Loading

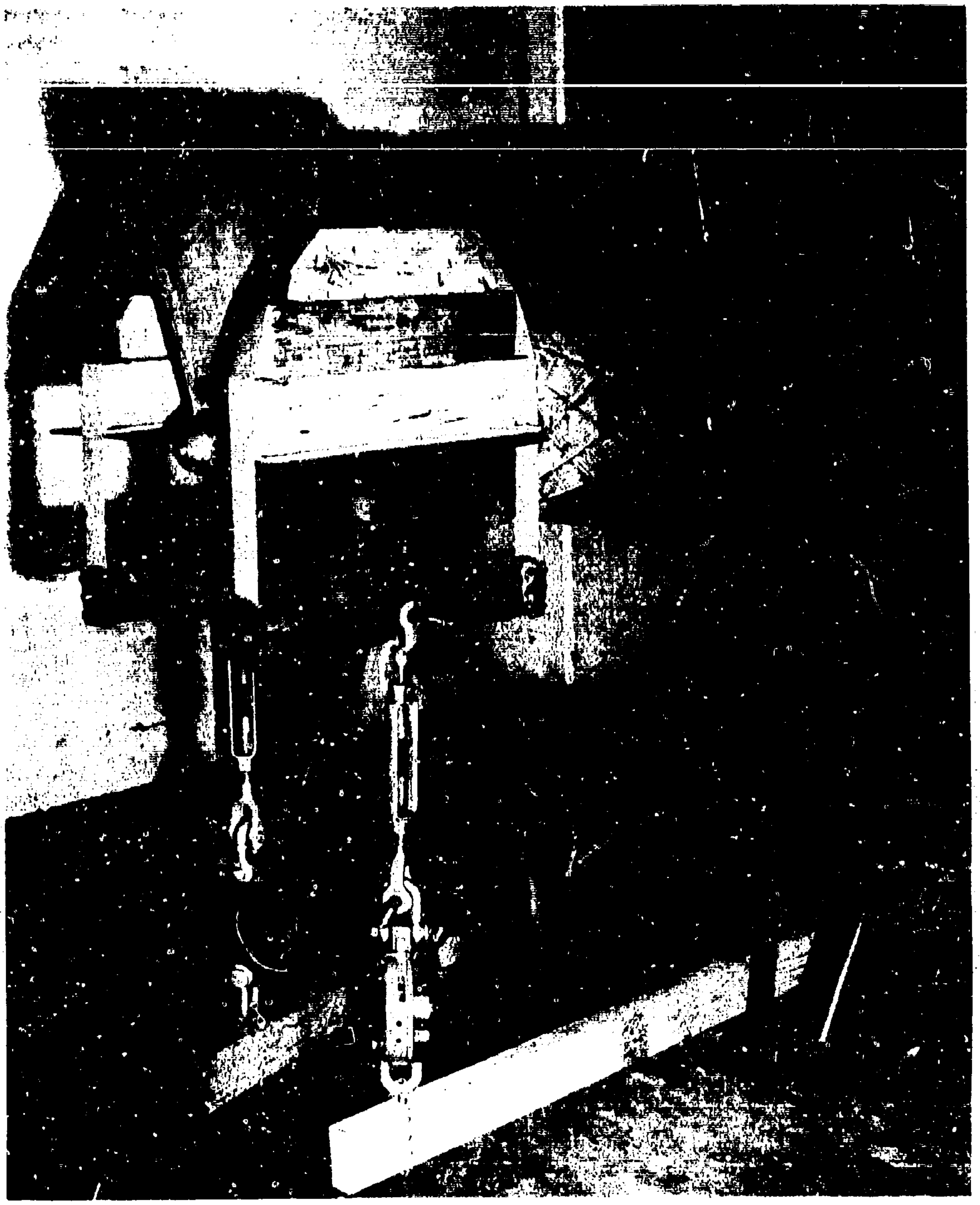


Figure 42. Test Setup for Tail Fin Loading

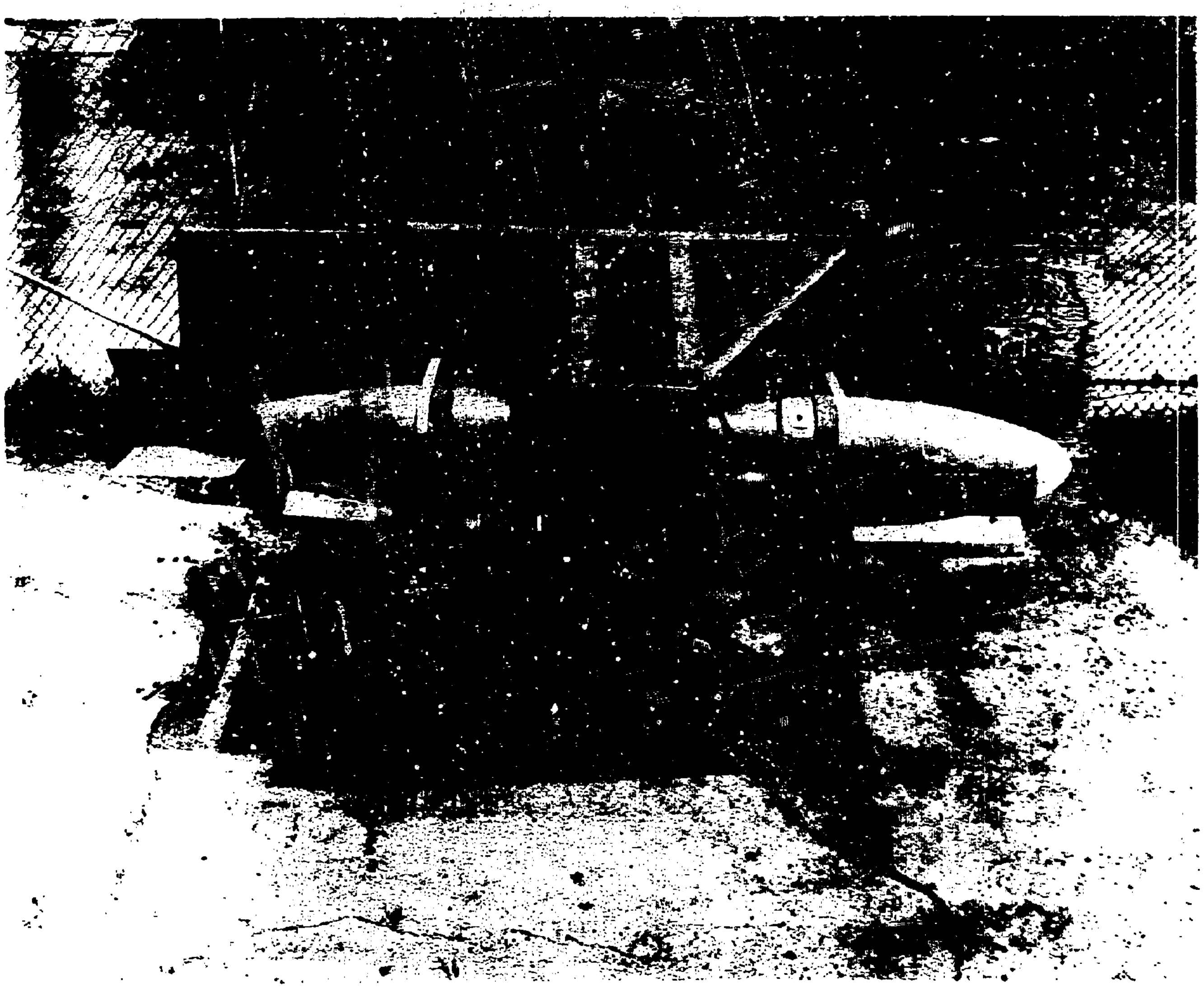


Figure 43. Test Setup for Flight Loads

Figure 44. Sway Brace Attachment

SECTION VII

RESULTS

The results in this section show each tank in numerical order.

S/N 001

Weight = 62 pounds

Dimensions

Outside Diameter = 18.53 in.

Tank Overall Length = 136 1/32 in.

Distance Between Mounting Rings = 14.00 in.

Tests Performed - None. Tank used as a display unit.

General Discussion

The tank was filament wound without difficulty; however, several attempts were made at forming the ABS plastic liner (winding mandrel) before an acceptable part was made. Difficulties were also encountered in locating the thermoformed plastic foam, used as a sandwich core between the GRP windings, which required the initial windings to be removed and an alternate method of forming the foam used.

The key to thermoforming the ABS plastic tubing into liners suitable for filament winding is to have good control over the forming temperature and rate.

The overall appearance of the tank was considered good for a first article. There were no problems in attaching the nose cap or tail fin assembly. Figure 45 shows the completed unit.

S/N 002

Weight = 59.0 pounds

Weight Full of Water = 903 pounds

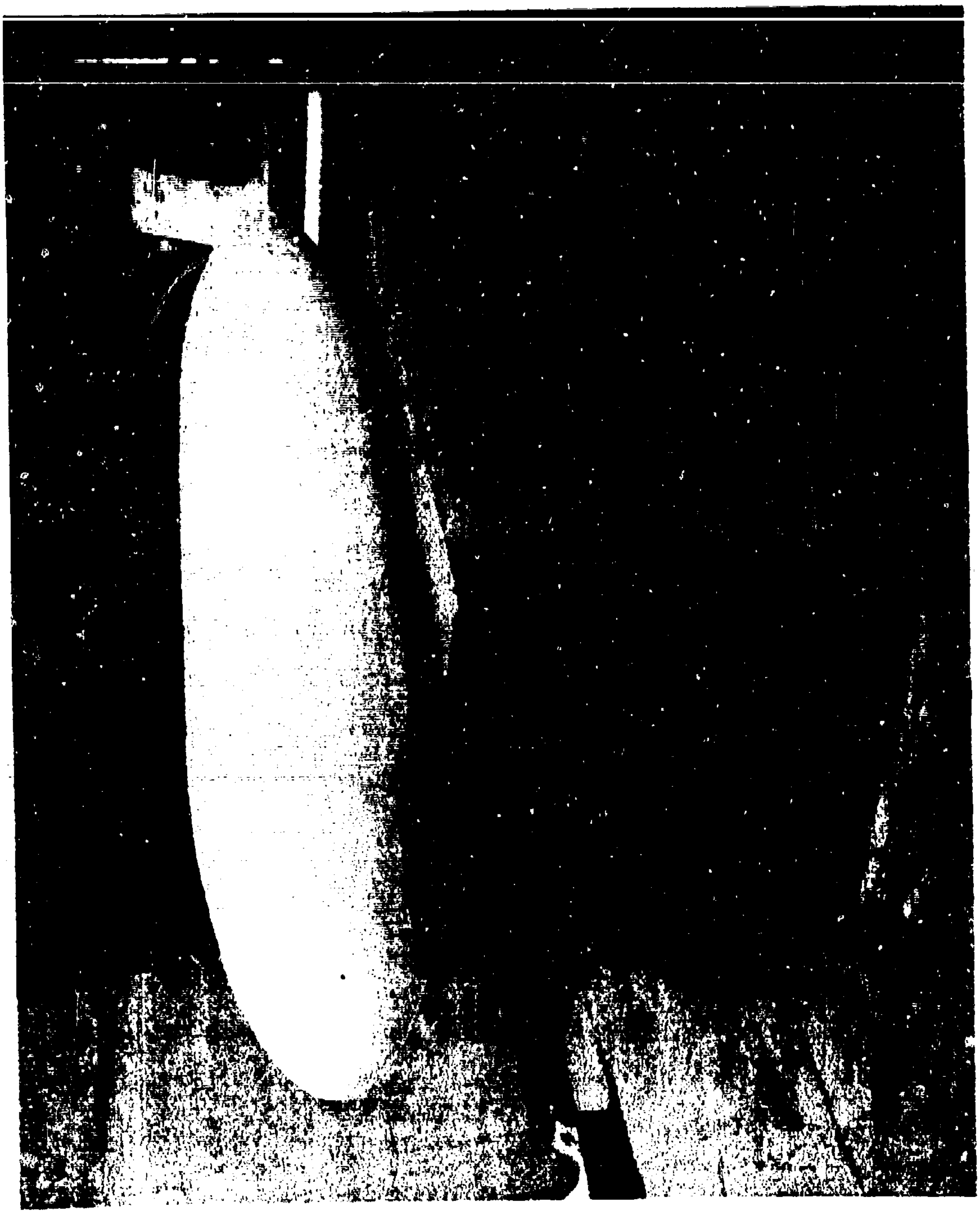


Figure 45. Tank, S/N 001, Completed

Internal Volume = $\frac{903-59}{8.33}$ = 101.3 gallons

Dimensions

Outside Diameter = 18.47 in.

Tank Length (Polar Ring to Polar Ring) = 115 5/8 in.

Tests Performed -

Maximum Lug and Sway Brace Loads (Cond. 1 in reference 7) - Ultimate loads applied with no damage.

Maximum Internal Frame Loads (Cond. 2 in reference 7) - Ultimate loads applied with no damage.

Maximum Shear and Bending Loads (Cond. 3 in reference 7) - Shell buckled locally under the straps (delamination area) at 99% of ultimate load.

General Discussion

The tank was wound on a sub-par liner (bladder) in that it was not completely formed around the frames and forward tapering section. Also, it made a poor fit with the polar rings. Attempts were made to correct the liner problems by forming in a larger radius in the deep drawn corner of the frames and the use of a heat gun to draw the liner out to shape.

The tank was wound with Air Force resin blend 542/4205/Tonox (see appendix III, FSCS-106) with very fine results due to improved pot life and lower winding viscosity. One percent BF_3MEA was used as an accelerator. Since the resin was used at a cool temperature, it was necessary to melt the BF_3MEA into warm Tonox. The finished wound tank did not cure readily under the infrared lamps and over eight hours were required to set or gell the resin. The curing required 36 hours with the temperature at approximately 275°F. The troubles with curing could have been either the poor mixing and ingestion of the BF_3MEA or resin with a higher gell temperature/longer time relationship than FSI has encountered previously.

Because of the high curing temperatures, a local area of the tank delaminated from the gassing of the PVC foam and several pin-hole blisters appeared in the internal liner in an area approximately twelve inches in diameter.

S/N 003

This tank was lost during cure because of a pressure loss which allowed the liner (bladder) to partially collapse prior to the resin being cured.

S/N 004

Tests Performed -

Internal Pressure -

1) 80 psig fill cap "O" ring blew out. Pin-hole liner leaks were evident at the frame area.
2) 80 psig using solid bulkhead plate instead of fill cap. Leakage in frame area of smaller amount.
3) 100 psig several times while efforts were made to stop leaks.
4) 125 psig failed in hoop tension through the line of tank fittings. Analysis of damage indicates an insufficient edge bond around the openings. (Edge distance was approximately 1/2".) Figure 46 shows the failed section.

General Discussion

This tank was manufactured with the greatest success yet achieved. The single-piece ABS liner was thermoformed successfully with the use of a foam radius in the deep drawn corners of the frames. The entire liner assembly was felt to be satisfactory. The winding was accomplished with a new program using a

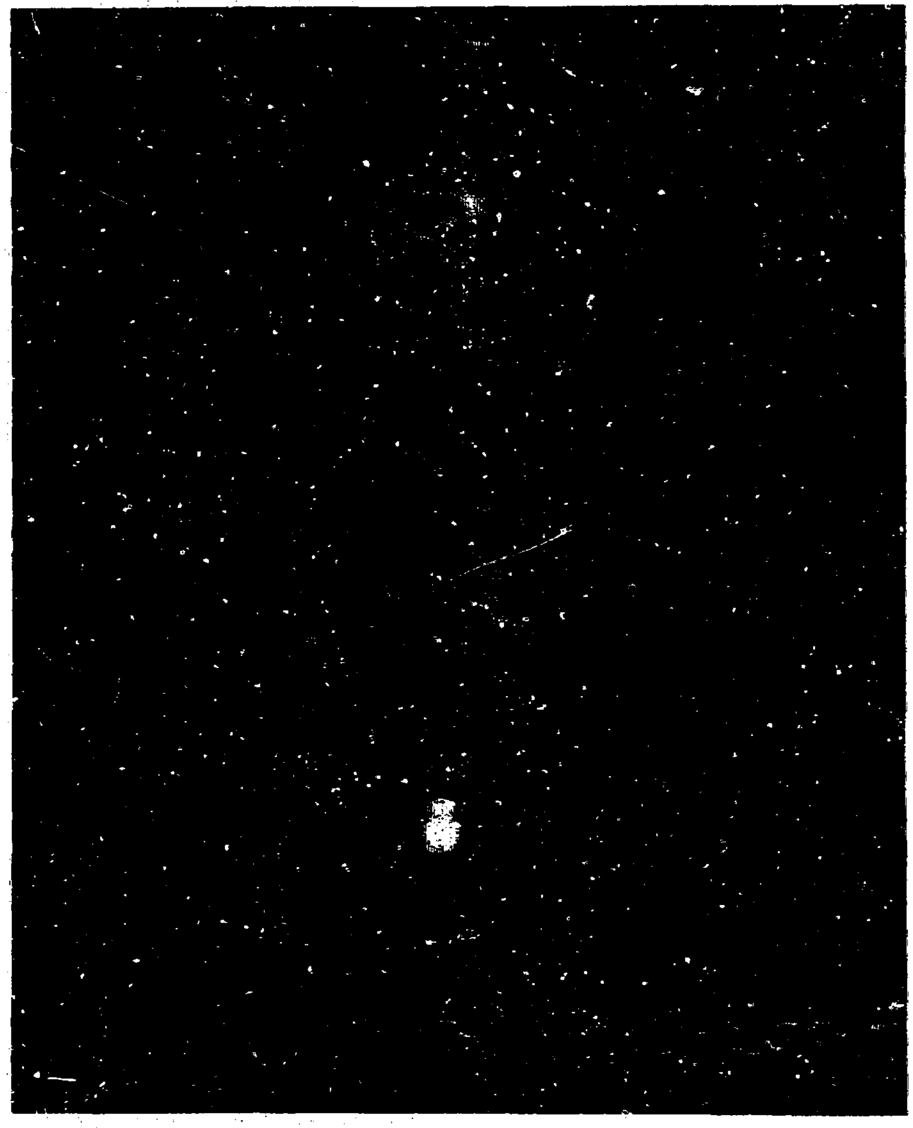


Figure 46. Tank, S/N 004, Failed Area

multiple circuit pattern of twelve circuits. The tank was fabricated with the resin system developed by FSI (see appendix III, FSCS-102) because of the lack of availability of one of the Air Force resin blend components. The tank was cured out successfully.

S/N 005

Weight = 53.13 pounds (without end caps and internal plumbing)

Dimensions

Outside Diameter = 18.50 in.

Tank Length (Polar Ring to Polar Ring) = 116 in.

Distance Between Mounting Lugs = 13.98 in.

Tests Performed -

Internal Pressure - 175 psi for 20 minutes. Leakage around frames caused foam to separate from windings.

General Discussion

The problems of forming and bonding the liner firmly and snugly around the frames and achieving a leak-tight structure in this area still remain as the major difficulties. Figure 47 shows a liner fracture.

The edge distance around the penetration (tank fittings) was increased from 1/2 inch to one inch, which appears to have solved the structural weakness problem through the penetrations experienced on tank S/N 004.

S/N 006 and S/N 007

Weight = 75 pounds each

Tests Performed -

Internal Pressure - 50 psig. Slight leaks around the fittings (both tanks.)

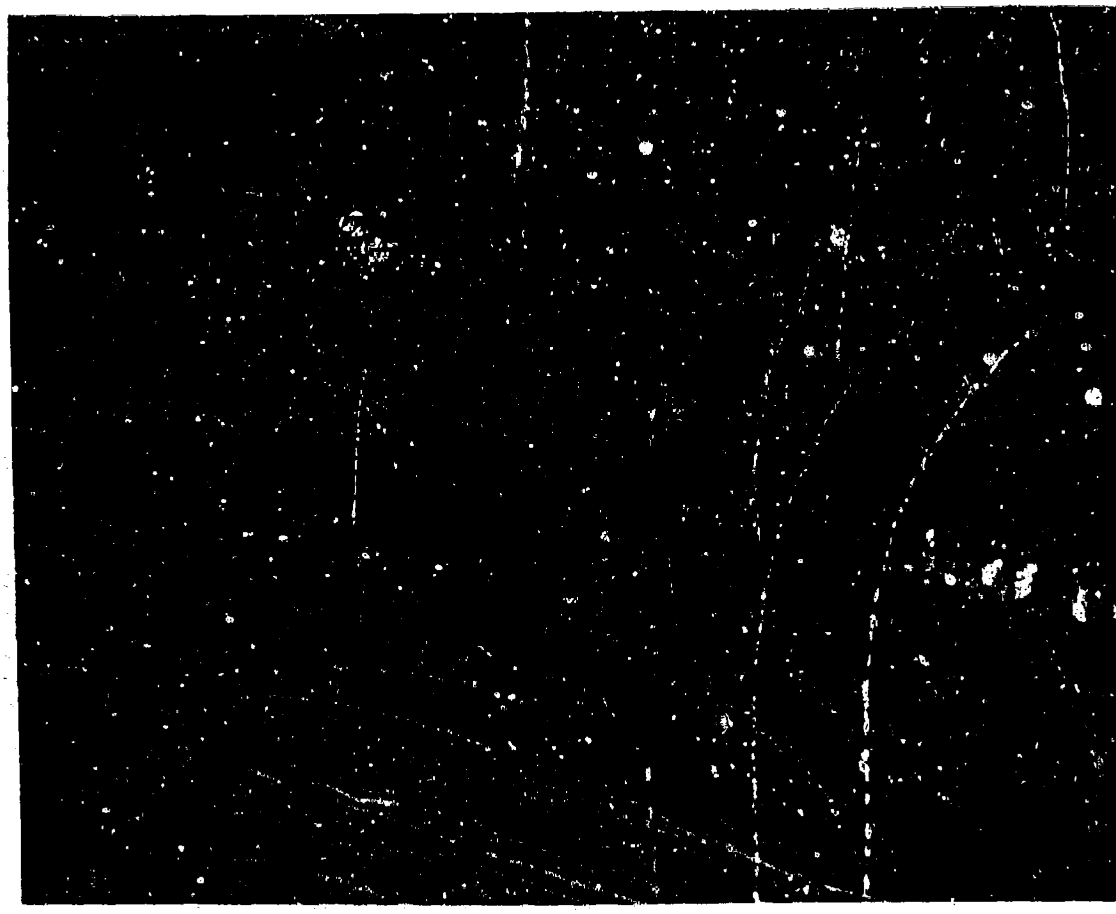


Figure 47. Tank, S/N 005, Liner Fracture

General Discussion

Tanks S/N 006 and 007 were wound on inferior (previously discarded) liners rather than hold up the program awaiting delivery of new material. This action was justified since these tanks were to be subjected to environmental, slosh and vibration testing at operating pressures of only 4 psig. Leakage through the liner, the problem area of concern, will not be apparent at this pressure. These tanks were somewhat out of shape because of the inferior liners. Also, the tank liner contained several patches and repaired areas. Figure 48 shows a liner repair area. Both tanks were shipped to WPAFB for environmental, slosh and vibration testing.

S/N 008

This tank was lost during cure because of a pressure loss which allowed the liner (bladder) to collapse. Post inspection of the failed tank revealed the winding hardware inside the tank did not fit properly and as the tank rotated, the hardware rubbed against the liner eventually causing it to rupture.

S/N 009

This tank was lost during the winding process when the liner failed by overstressing. The liner did not fit tightly around the frames, thus it was not supported by the glass windings. The failure took place when the internal pressure was increased to 20 psig.

S/N 010

Weight = 46.0 pounds (no fittings, plumbing or end caps)

Weight = 63.0 pounds (total assembly)

Weight Full of Water = 921 pounds

$$\text{Internal Volume} = \frac{921-63}{8.33} = 103.0 \text{ gallons}$$

Figure 48. Liner Repaired Area

Dimensions

Outside Diameter = 18.51 in.

Tank Length (Polar Ring to Polar Ring) = 115 7/8 in.

Distance Between Mounting Lugs = 13.98 in.

Distance to CG = 9.38 in. forward aft lug

Tests Performed -

External Pressure - 3.0 psig to 10 minutes, 0.5 in. Hg. decay in 10 mins.*

Leak - 15 psig internal pressure for one hour. No leakage

Internal Pressure - 150 psig for one minute. Leakage around one of the fittings was noted as the pressure was being released. There was no structural damage to the tank.

Maximum Lug and Sway Brace Loads (Cond. 1 in reference 7) - Ultimate loads applied with no damage. The non-loaded sway brace pads each raised off from the tank's surface a distance of 0.129 inches at ultimate load. At no load the sway brace pads were slightly preloaded.

Maximum Internal Frame Loads (Cond. 2 in reference 7) - Ultimate loads applied with no damage. The non-loaded sway brace pads raised off from the tank's surface distances of 0.094 and 0.098 inches.

Maximum Shear and Bending Loads (Cond. 3 in reference 7) - Ultimate loads applied with no damage.

Tail Fin Loads - 1) Maximum loads in same direction normal to horizontal fins (Cond. A in reference 7). Ultimate loads applied with no damage.

*Probably due to minor leaks in setup.

2) Maximum loads in opposite directions normal to horizontal fins (Cond. B in reference 7). Ultimate loads applied with no damage.

3) Maximum loads normal to vertical fin (Cond. C in reference 7). At 82.5% of ultimate loads slight cracking was heard, test was terminated since it was not desired to fail the specimen.

General Discussion

This tank was wound on a near-perfect liner. The only manufacturing problem was the long time (24 hours) required to cure the resin. Testing to ultimate loads was performed satisfactorily except the vertical tail fin was loaded only to 82.5% of ultimate loading and a leak developed around one of the fittings as the pressure was being lowered from ultimate (150 psi). Figure 49 shows the tank undergoing structural testing.

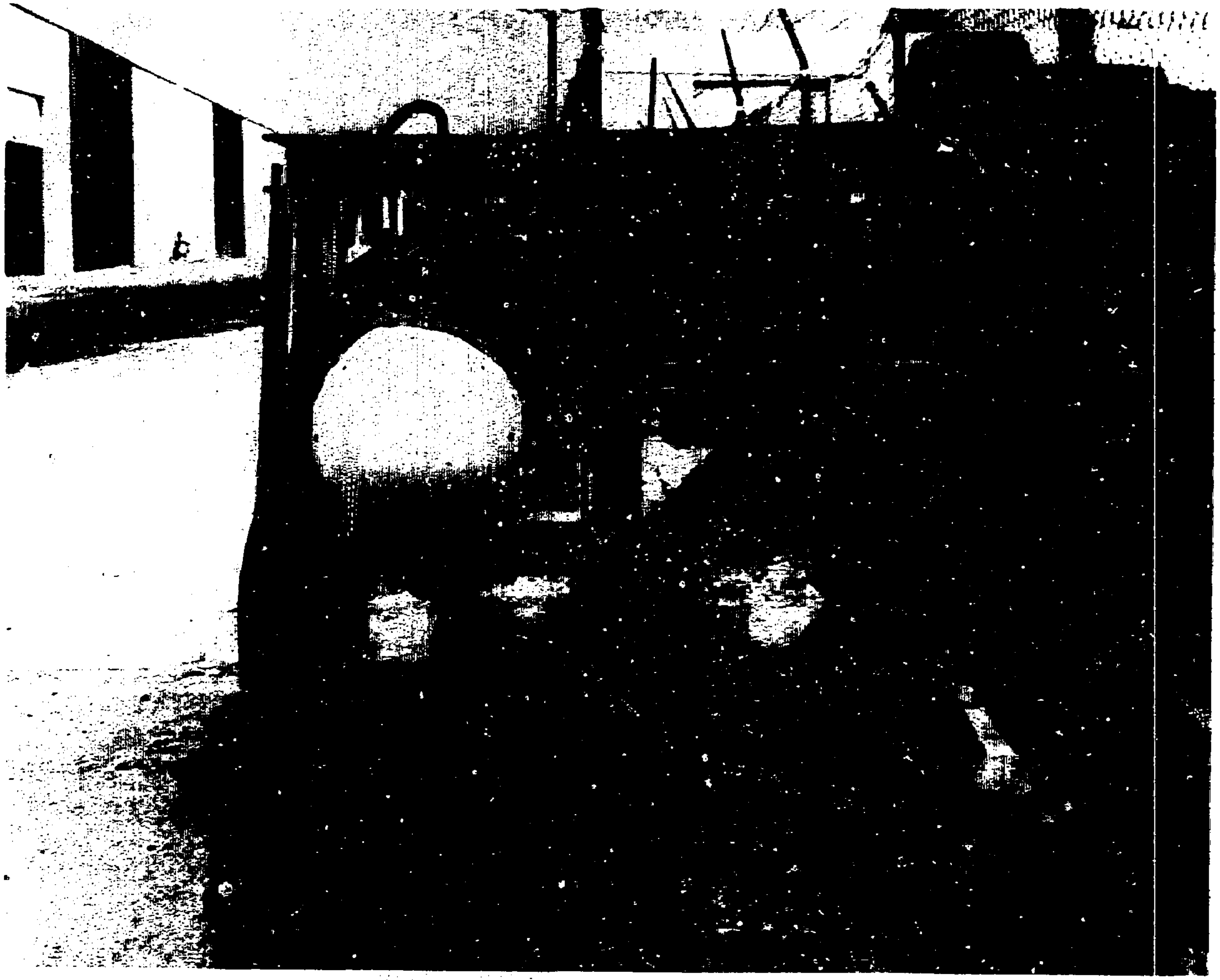


Figure 49. Tank, S/N 010, Undergoing Structural Testing

SECTION VIII

COST ANALYSIS

The Air Force Work Statement, contained in Contract F33615-68-C-1622 requires the submittal of a detailed Cost Analysis of the 100 gallon filament wound tank. This analysis, due at the completion of the contract and with the final report, is to be used to determine the cost of volume production of reinforced plastic wing tanks.

The information to follow in this cost section is based upon the knowledge and experience of Fiber Science- - -gained during the execution of the Air Force contract and with similar low volume commercial contracts. The estimates are presented primarily as learning curves since neither FSI nor any other company has direct, related, high-volume production experience to rely upon.

A learning curve of 85% is used to reflect the cost reductions of volume production. The 85% curve is applied to the costing of both materials and labor. The reader may question the use of an 85% factor applied on the overall when materials are such a large percentage of the cost of the product. The multitude of hardware and parts, however, make up most of the materials cost and are subject to very high cost reductions in volume production.

The costing is broken down as follows:

A. Non-Recurring Costs

1. Engineering
2. Tooling
3. Amortization of Capital Equipment

B. Recurring Costs

1. Raw Materials

2. Parts and Hardware

3. Labor

C. Burden Rate

Estimated for a typical installation at 120%.

D. General and Administrative Rate

Estimated for a typical installation at 25%.

E. Profit

Equal to 10% markup.

The learning curve is extrapolated to include up to 4,000 tanks production. The curve shows the materials, labor and burden to which the G & A and profit must be added. The labor rate used in the curve is considered an average for the next two years at $3.75/hr.

A fixed point production is chosen for the evaluation of total tank cost, including non-recurring costs, at the following:

1. A production rate of four tanks/shift.
2. A production rate assuming 240 shift/year.
3. A two year contract totaling 4 x 240 x 2 = 1920 tanks.

The non-recurring costs of engineering, tooling, and capital equipment depreciation are based on the rate of 4/shift and the total of 1920 units.

The estimated non-recurring follows:

A.	Engineering		$ 40,000.00
B.	Tooling consisting of:		
	Liner Forming Mold	$ 7,500.00	
	Liner Oven & Support Hardware	3,000.00	
	Winding Hardware - 12 sets @ $800.00/set	9,600.00	
	Frame Ring Mold = 16 @ 1,260.00	20,200.00	
	Nose Cone Mold	160.00	
	Polar Ring Mold	3,000.00	
	Closure Mold	4,000.00	
	Foam Mold	5,000.00	
	Doubler Molds	4,000.00	
	Molar Mold	5,000.00	
	Tree Form Mold	1,000.00	
	Housing Adapter Molds	5,000.00	
	Tail Cone Molds = 8 @ $3,000.00	24,000.00	
	Bracket Molds	2,500.00	
	Adapter Molds	1,000.00	
	Foam Core Mold	1,000.00	
	Total Tooling:		95,960.00
C.	Qualification		8,000.00
D.	Amortization of Capital Equipment with 5 year depreciation		36,000.00
			$179,960.00

Amortizing the non-recurring over 1920 tanks

$$\frac{179,960}{1920} = \$94.00$$

The recurring costs are estimated for a production of 32 tanks. The learning curve is extrapolated in both directions at the 85% level.

Recurring Costs

1. Raw Materials

Liner	$ 12.00	
E Glass Roving	30.00	
Style 181 Glass Fabric	15.00	
PVC Foam	36.00	
Foam-In-Place Foam	2.00	
Epoxy Resin	65.00	
Adhesives	10.00	
	170.00	
10% Material Burden	17.00	
Total Raw Materials		$187.00

2. Parts & Hardware

Nose Cone	$ 2.00	
Aft Mounting Ring Inserts	2.00	
Forward Mounting Ring Inserts	2.00	
Suspension Lug	3.00	
Drain Valve Housing	1.00	
Fill Cap Housing	5.00	
Electrical Receptacal Housing	1.00	
#16 Coupler Housing	.30	
#12 Coupler Housing	.60	
Drain Tube Bracket	4.00	
Shut-off Valve Bracket	10.00	
Float Switch Bracket	2.00	
Vent Tube Bracket	1.80	
Shut-off Valve Adaptor	8.00	
Fill Cap Adaptor	1.50	
#16 Check Valve Tubing	4.00	
#12 Drain Tubing	5.00	
#6 Vent Tubing	3.00	
#6 Float Switch Tubing	4.00	
End Closure	12.00	
Drain Cork (Koehler)	3.00	
Float Switch (Koehler)	21.50	
Fuel Shut-off Valve (Koehler)	82.50	
Fuel Check Valve (Crissair)	20.22	
Tank Cap (Shaw)	12.62	
#16 Threadseal	.45	
#12 Threadseal	.30	
Wiggins Coupler	13.88	
Wiggins Coupler	11.38	
Wiggins Coupler	7.94	
#16 Manifold Elbow 90°	7.23	
#16 Manifold Elbow 45°	7.14	
Electrical Receptacle	.49	
O-Ring	1.50	
Miscellaneous Bolts	15.00	
Polar Rings	20.00	
Core Reinforcing Doublers	25.00	
Support Ring Molar	16.00	
Tree Foam Close Out	6.00	
		$344.35
Parts and Hardware Overhead 10%		34.43
Total Parts and Hardware:		$378.78

3. Labor

	Man Hours
Liner Forming	6
Frame Laminating & Foaming	8
Tail Cone Laminating	20
Foam Forming, Trim & Placement	16
Tank Winding	12
Tank Assembly	32
Proof Testing	4
	98

98 man hours	x	\$3.75/hr	=	\$367.00
120% Burden			=	440.00
				\$807.00

The total manufacturing cost at the 32/tank quantity is:

Raw Material	\$ 187.00
Parts and Hardware	379.00
Labor and Burden	807.00
	\$1,373.00

The learning curve will be initiated at \$1,373.00/tank at a quantity of 32 tanks.

Typical tank cost for the filament wound unit would be:

A. 32 Units

From curve,	\$1,373.00	
25% G & A	344.00	
	\$1,717.00	
10% Profit	172.00	
	\$1,899.00	+ non-recurring

B. 500 Units

From curve	\$722.00	
25% G & A	180.00	
	\$902.00	
10% Profit	90.00	
	\$992.00	+ non-recurring

C. 1,000 Units

From curve	$614.00
25% G & A	153.00
	$767.00
10% Profit	77.00
	$844.00 + non-recurring

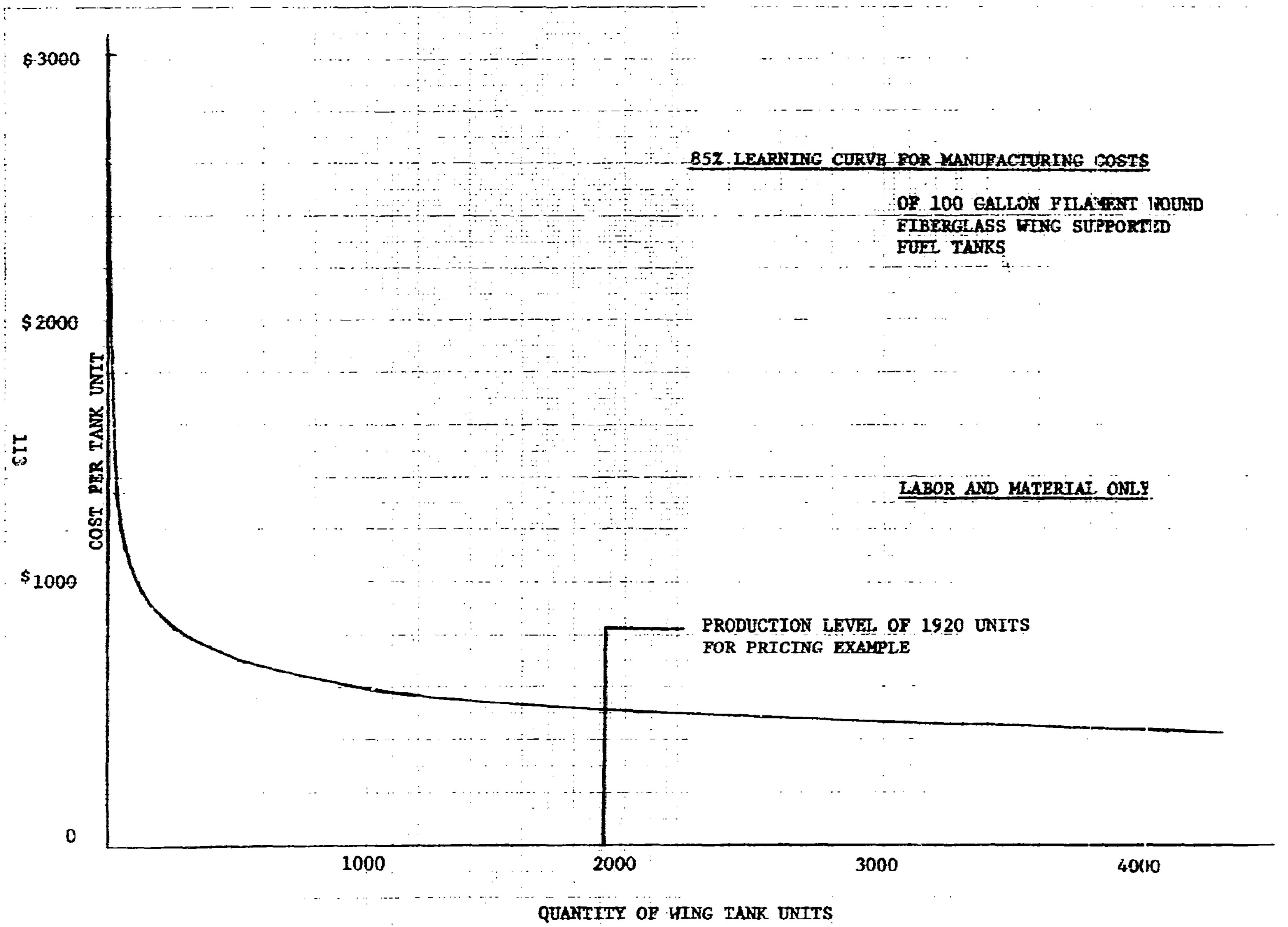
D. 1,920 Units

From curve	$527.00
25% G & A	132.00
	$659.00
10% Profit	66.00
	$725.00 + non-recurring

E. 4,000 Units

From curve	$444.00
25% G & A	111.00
	$555.00
10% Profit	55.00
	$610.00 + non-recurring

The cost of 1920 units with non-recurring expenses as determined earlier is $725.00 plus $94.00, equaling $819.00.


85% LEARNING CURVE FOR MANUFACTURING COSTS
OF 100 GALLON FILAMENT WOUND FIBERGLASS WING SUPPORTED FUEL TANKS
LABOR AND MATERIAL ONLY
PRODUCTION LEVEL OF 1920 UNITS FOR PRICING EXAMPLE
$3000
$2000
$1000
0
COST PER TANK UNIT
1000
2000
3000
4000
QUANTITY OF WING TANK UNITS

SECTION IX

CONCLUSIONS

1. The feasibility of fabricating GRP filament wound wing tanks over an inflated liner (bladder) was proven.

2. The GRP wing tanks with refinements to manufacturing processes are approximately 40% lighter in weight than aluminum foam-filled tanks having the same capacity.

3. Assembly of the internal plumbing and fittings was not a problem.

4. There were no structural deficiencies with the design, and the tanks met the design criteria. The structural failures that were encountered were all accountable by defects in fabrication and were corrected in final design.

5. No problems were encountered with filament winding process in winding of the tanks.

6. The primary resin system used (see Appendix III, FSCS-106) required a longer curing time than previously encountered by FSI and appears to yield a very brittle structure which is easily damaged.

7. The tank design, tooling and manufacturing processes developed in this program can be used without modification to fabricate wing tanks which will withstand all the design ultimate loads.

SECTION X

RECOMMENDATIONS

1. The cross-sectioned geometry of the frames be changed to minimize sharp corners.

2. The frames should be fabricated around the liner (bladder) rather than forming the liner around prefabricated frames.

3. It is recommended that the tank be redesigned around high production manufacturing processes.

4. It is recommended that the liner (bladder) be studied to determine the best forming techniques and to define other candidate materials.

5. It is recommended that the liner be treated to eliminate its elastic memory.

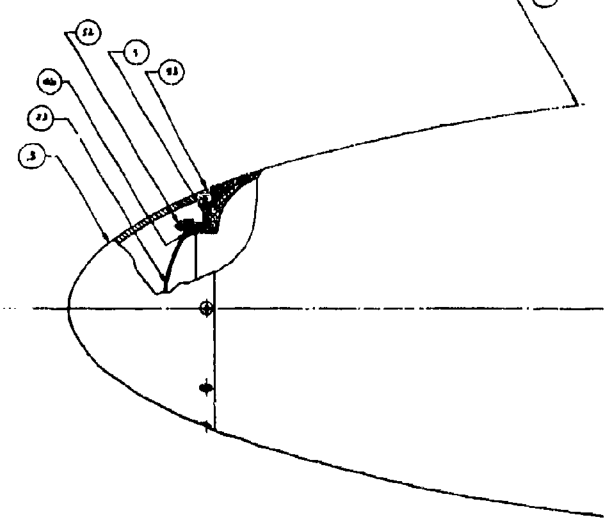
APPENDIX I

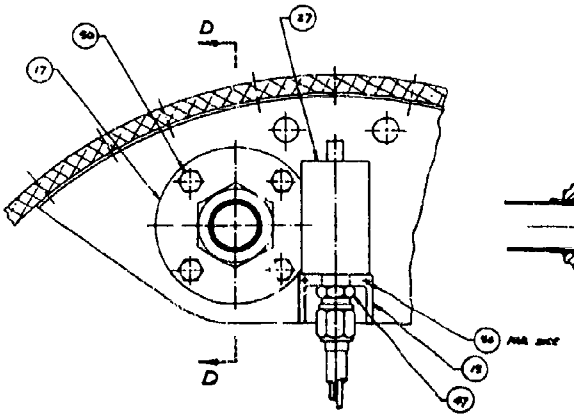
DRAWINGS

DRAWING LIST - AIR FORCE WING TANK

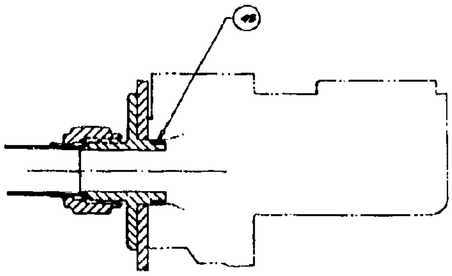
Drawing Number	Title
14-XT-001	Wing Tank Assembly
14-TX-002	Wing Tank Sub-Assembly
14-TX-003	Tail Cone Assembly
14-TX-004	Support Ring Assembly
14-T-005	Nose Cone
14-T-006	Polar Ring
14-T-007	Closure, End
14-T-008	Liner, Wing Tank
14-T-009	Ring, Mounting
14-T-010	Foam Cores, Tank
14-T-011	Doublers, Core Reinforcing
14-T-012	Molar, Support Ring
14-T-013	Tree, Foam Closeout
14-T-014	Lug, Suspension
14-T-015	Housings - Adaptor
14-T-016	Liner, Tail Cone
14-T-017	Brackets, Plumbing
14-T-018	Adaptors
14-T-019	Core, Tail Mounting
14-T-020	Tubings, Fuel Control
14-T-021	Foam Core, Support Ring Assembly

19	18	17	16





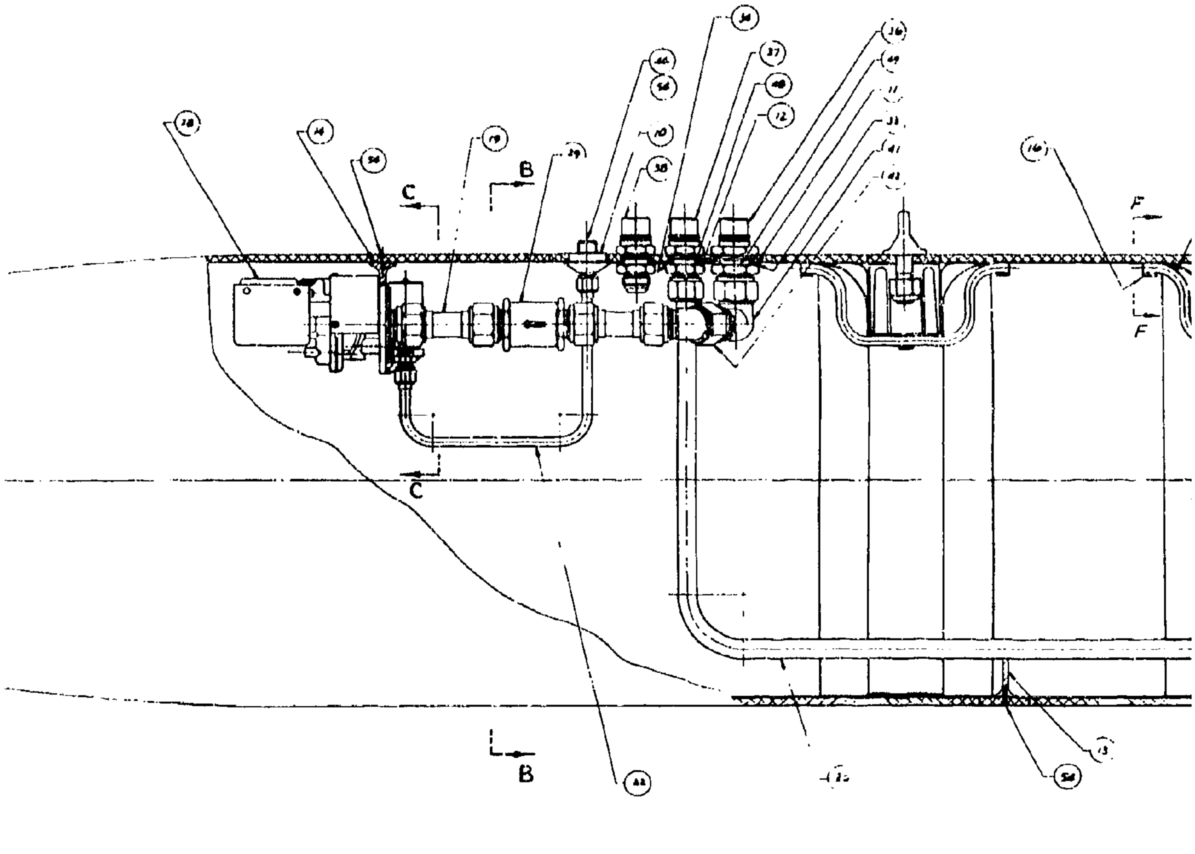
SECTION C-C
SCALE 1/1

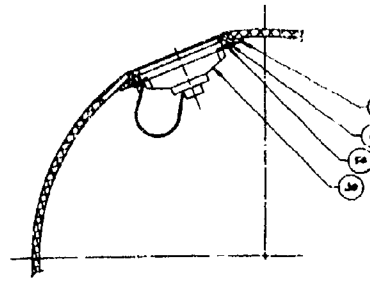


SECTION D-D
SCALE 1/1

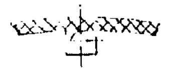
19	18	17	16

15 14 13 12 11



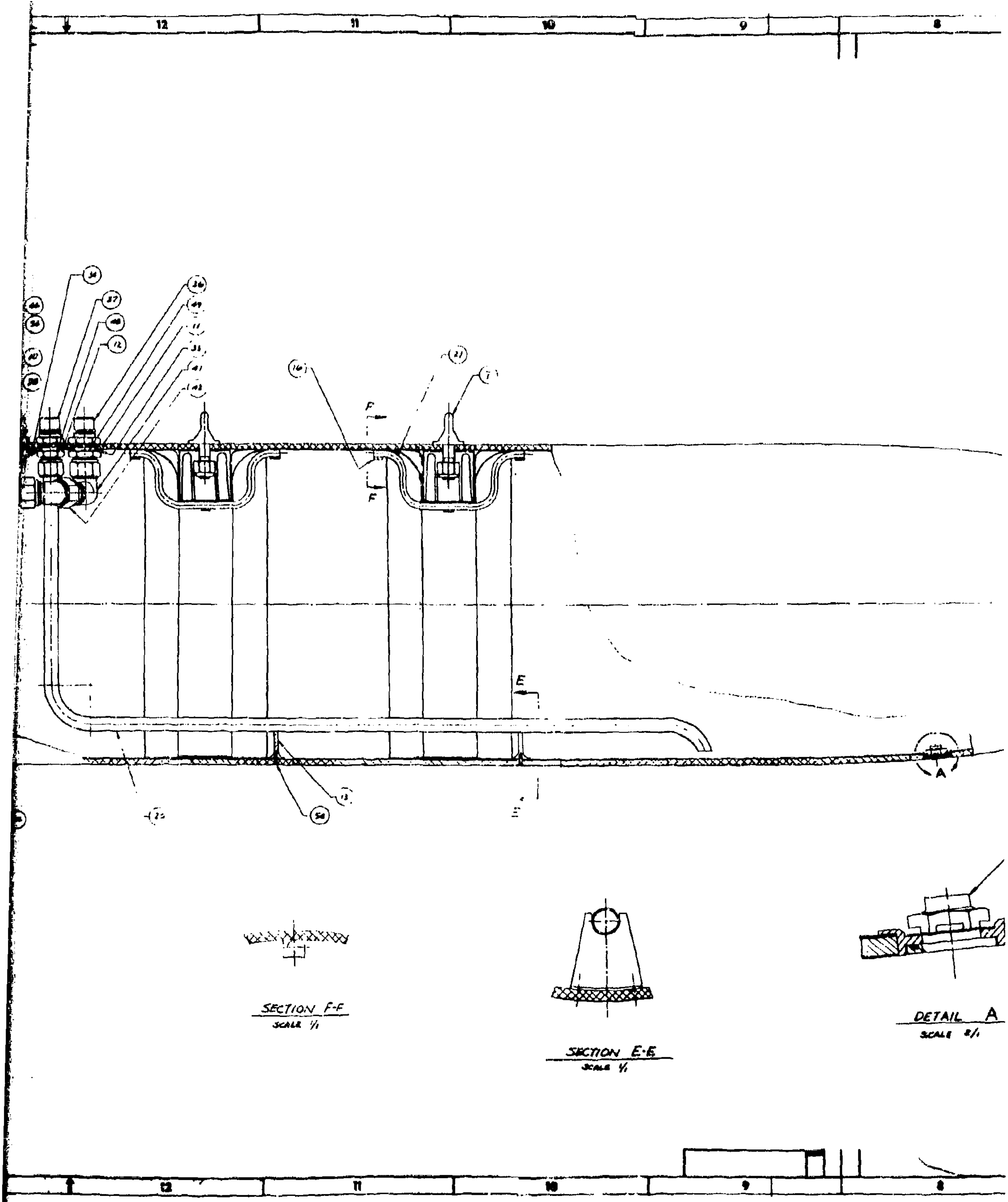


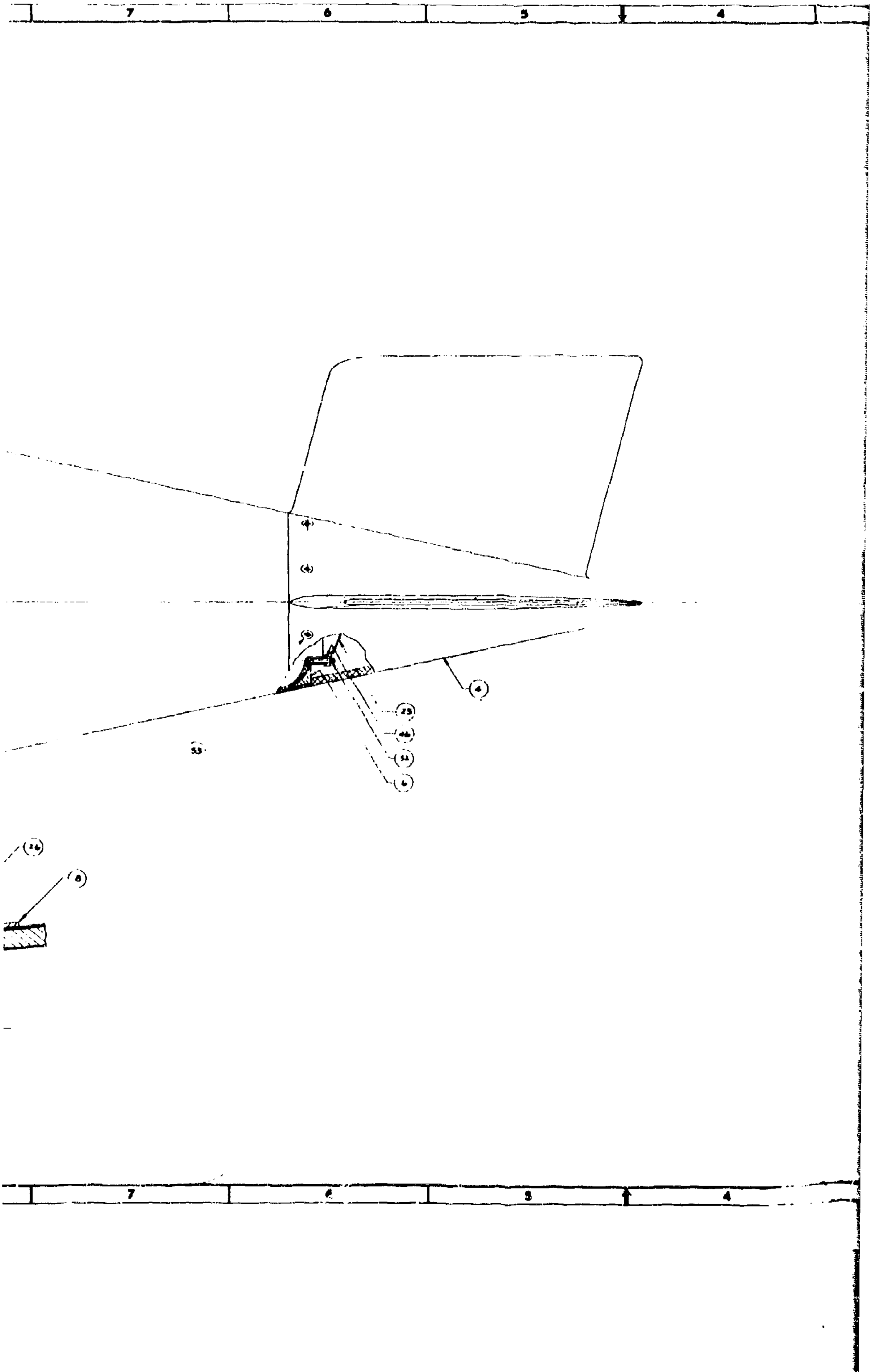
SECTION B-B

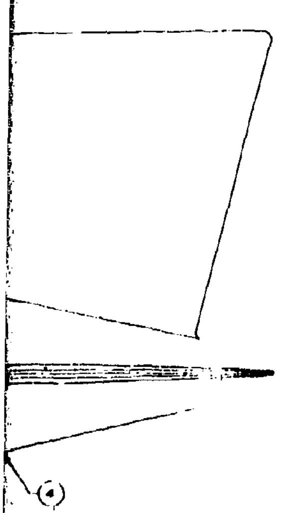


SECTION F-F
SCALE 1/1

15 14 13 12 11


12
11
10
9
8
F
E
A
SECTION F-F
SCALE 1/1
SECTION E-E
SCALE 1/1
DETAIL A
SCALE 2/1


7
6
5
4



QTY	PART NO.	NOMENCLATURE	MATERIAL	SPECIFICATION	ITEM NO.
					57
					[illegible]
					55
AR		SCREW, SELF-TAPPING, NO. 6			54
16		SCREW, FLAT HD. [illegible]			53
[illegible]	59 PH-832	NUT, [illegible]			52
					51
4		BOLT, HEX. HD. [illegible] -18			50
1	MS [illegible]-16	NUT			49
1	MS [illegible]-12	NUT			48
1	MS [illegible]-6	NUT			47
1	MS 9714-[illegible]	O-RING			46
1	MS 29[illegible]-[illegible]	O-RING			45
1	MS 31018	RECEPTACLE, ELEC			44
					43
1		ELBOW, MANIFOLD, 45°, #16			42
1		ELBOW, MANIFOLD, 90° #16			41
					40
					39
1	BC 106 E 17	COUPLER, WIGGINS			38
1	JP 403 E 16	COUPLER, WIGGINS			37
1	JP 3AE E 16	COUPLER, WIGGINS			36
					35
2		THRD SEAL, #12			34
1		THRD SEAL, #16			33
.					32
					31
1	457-2	CAP, TANK, [illegible]			30
1	2 3 30 16	VALVE, FUEL CHECK, [illegible]			29
1	7-[illegible]	VALVE, FUEL SHUT-OFF, [illegible]			28
1	1-[illegible]	SWITCH, FLOAT, [illegible]			27
1	3-[illegible]-1	COCK, DRAIN, [illegible]			26
					[illegible]
					25
					24
2	14-T-007	CLOSURE, END			23
1	14-T-006-7	TUBING, #6 FLOAT SWITCH			22
2	14-T-006-5	TUBING, #6 VENT			21
1	14-T-006-3	TUBING, #12 DRAIN			20
2	14-T-006-1	TUBING, #16 CHECK VALVE			19
1	14-T-005-1	ADAPTER, FILL CAP			18
1	14-T-005-3	ADAPTER, SHUT-OFF VALVE			17
6	14-T-017-7	BRACKET, VENT TUBE			16
1	14-T-017-5	BRACKET, FLOAT SWITCH			15
1	14-T-017-3	BRACKET, SHUT-OFF VALVE			14
2	14-T-017-1	BRACKET, DRAIN TUBE			13
2	14-T-015-9	HOUSING, #12 COUPLER			12
			PRELIMINARY DRAWING		
1	14-T-015-7	HOUSING, #16 COUPLER	FOR REFERENCE ONLY		11
1	14-T-015-5	HOUSING, ELEC. RECEPTACLE			10
1	14-T-015-3	HOUSING, FILL CAP			9
1	14-T-015-1	HOUSING, DRAIN VALVE			8
2	14-T-010	LUG, SUSPENSION			7
1	14-T-009-3	RING, MOUNTING, AFT			6
1	14-T-009-1	RING, MOUNTING, FWD			5
1	14-TH-[illegible]	TAIL CONE ASSY			4
1	14-T-002	CONE, NOSE			3
1	14-TH-002	WING TANK SUBASSY			2
	-1	WING TANK ASSY			1
-1	PART NO.	NOMENCLATURE	MATERIAL	SPECIFICATION	

LIST OF MATERIALS

DO NOT SCALE

J. [illegible]

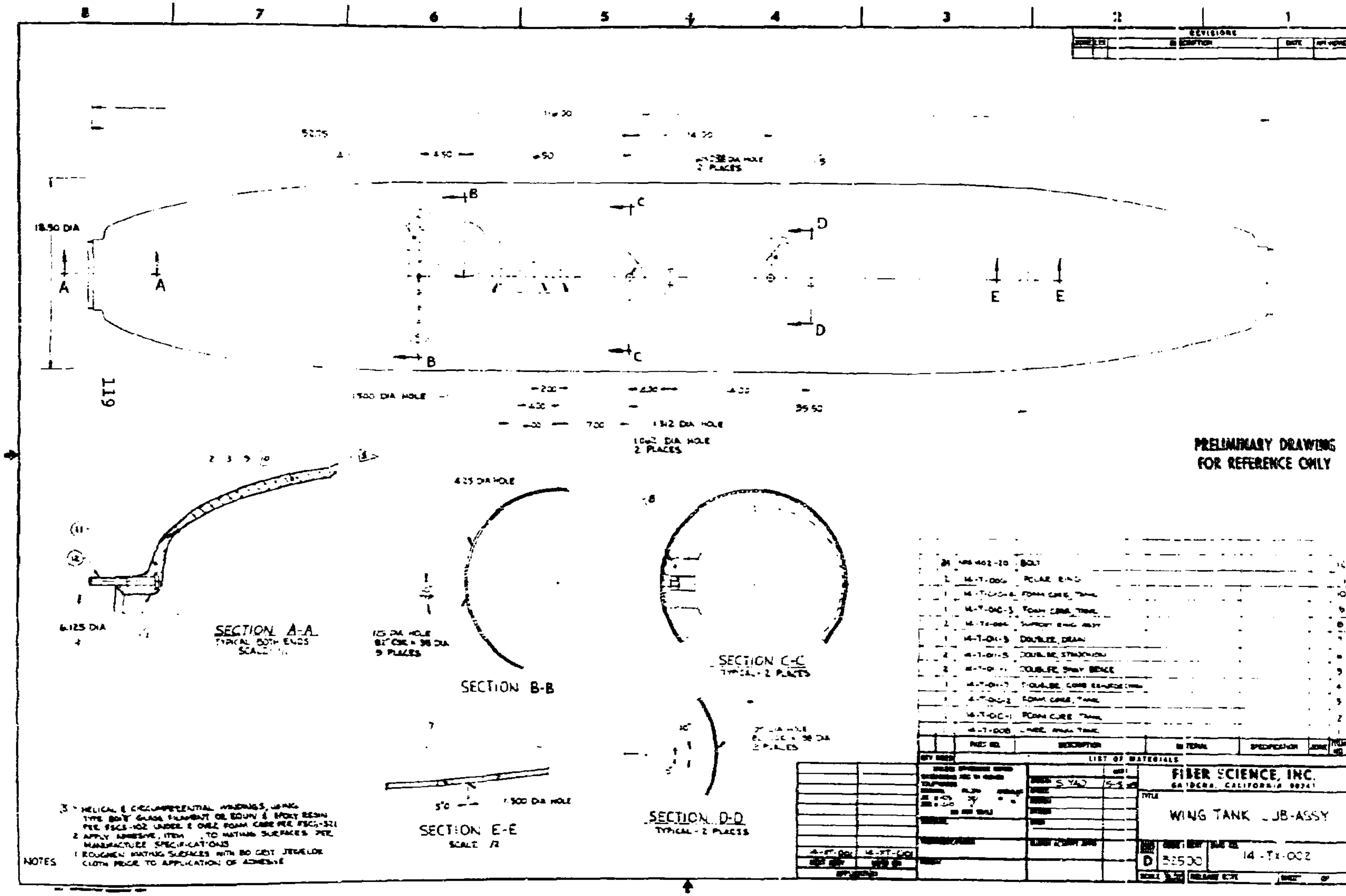
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA [illegible]

WING TANK ASSY

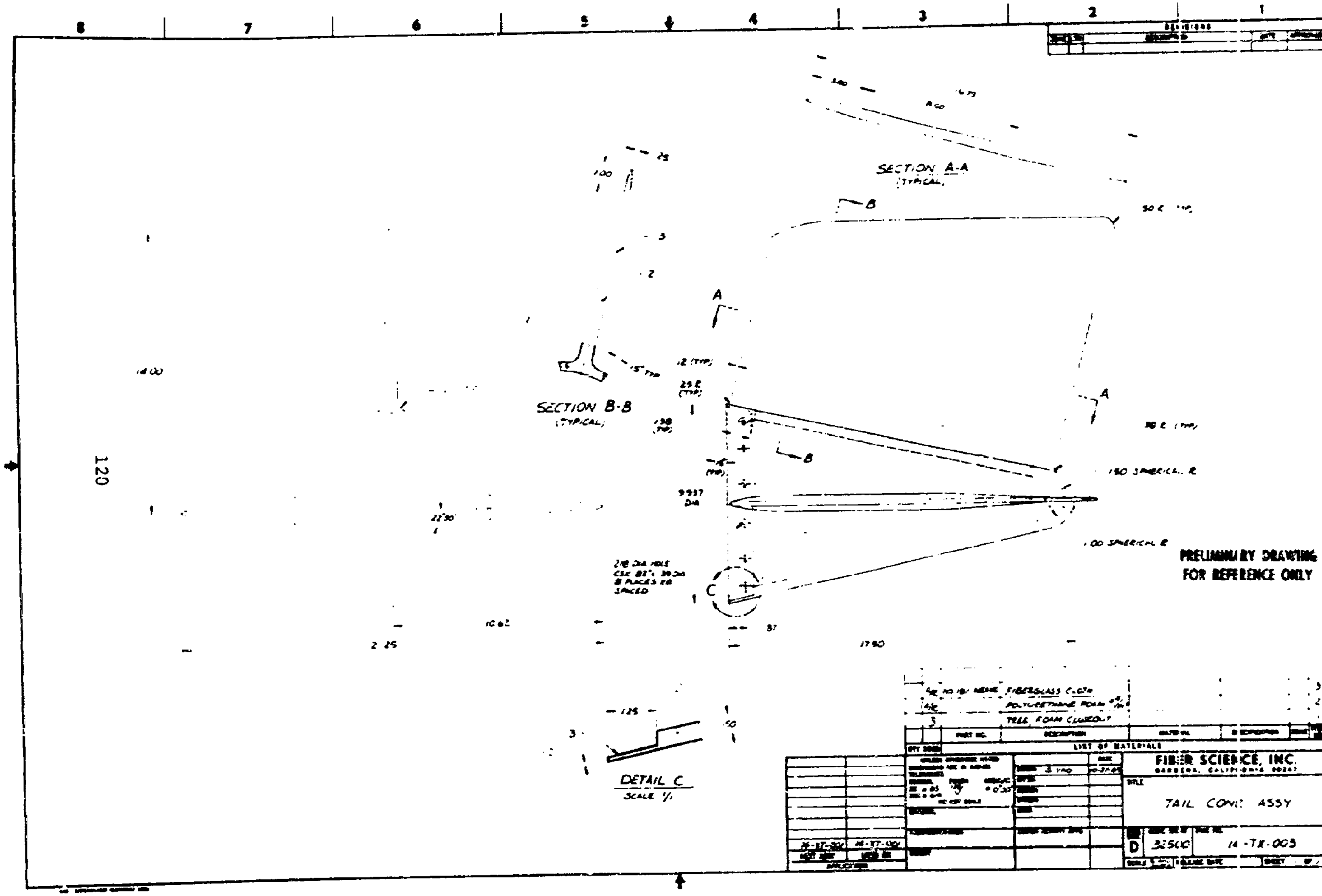
D 32500 14-XT-001

14-XT-001

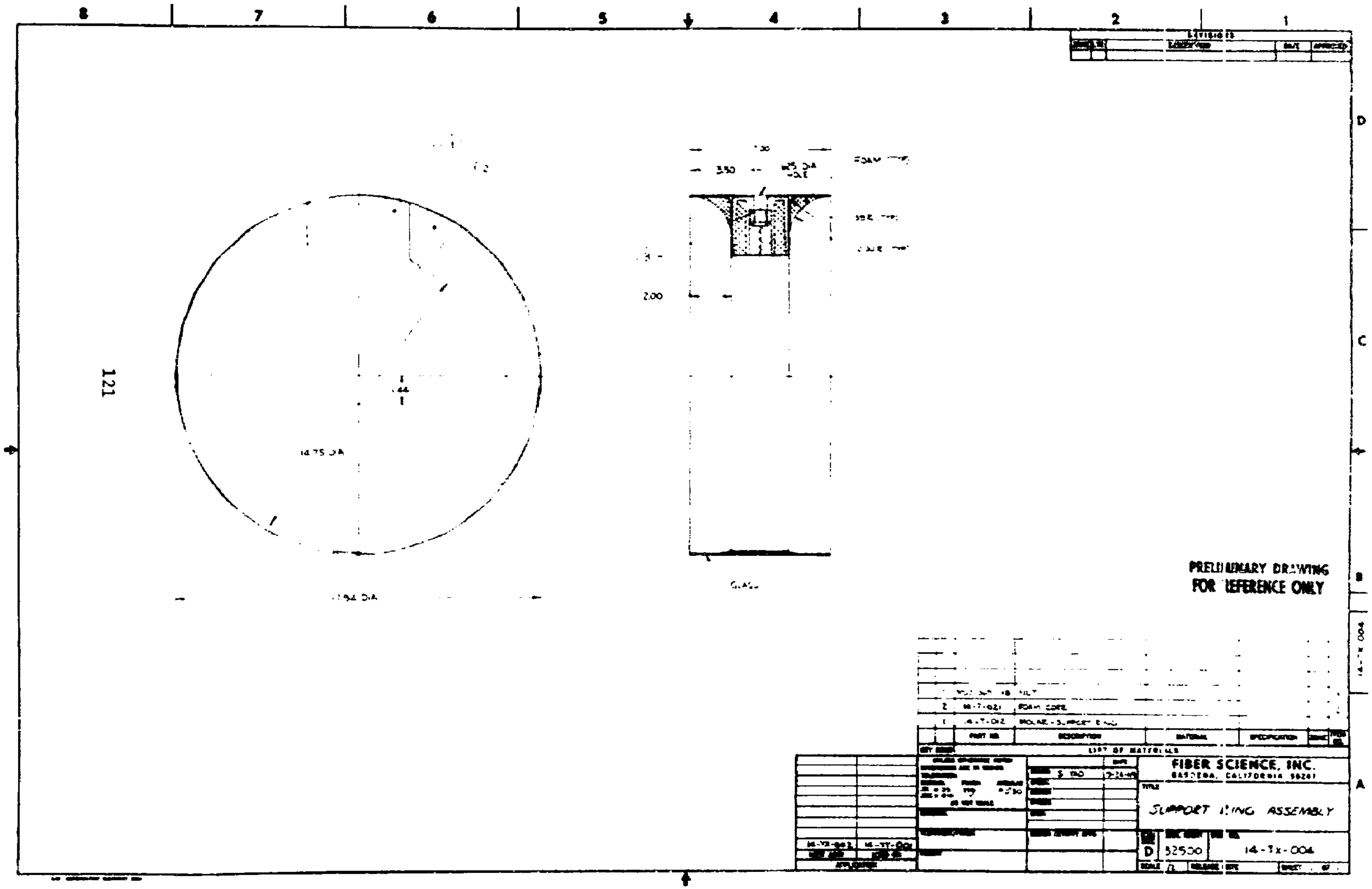
117

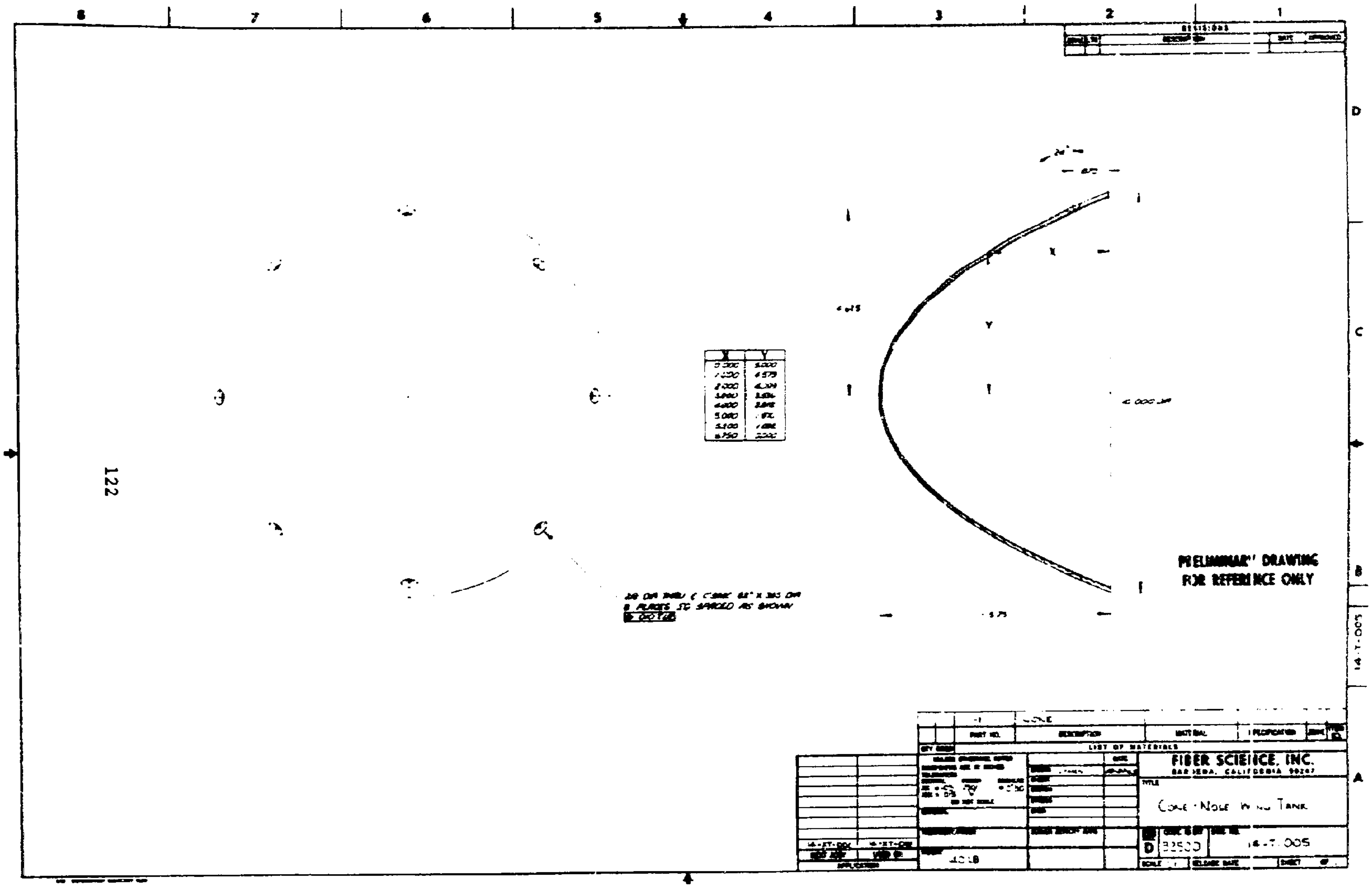

PRELIMINARY DRAWING
FOR REFERENCE ONLY
18.50 DIA
SECTION A-A
TYPICAL BOTH ENDS
6.125 DIA
SECTION B-B
.125 DIA HOLE
SECTION C-C
TYPICAL - 2 PLACES
SECTION D-D
TYPICAL - 2 PLACES
SECTION E-E
.500 DIA HOLE
1.312 DIA HOLE
2 PLACES
35.50
NOTES
3. HELICAL & CIRCUMFERENTIAL WINDINGS
2. APPLY ADHESIVE
1. ROUGHEN MATING SURFACES
BOLT
POLAR RING
FOAM CORE, TANK
SUPPORT RING ASSY
DOUBLER, DRAIN
LIST OF MATERIALS
FIBER SCIENCE, INC.
WING TANK SUB-ASSY
D
14-TX-002
REVISIONS

119

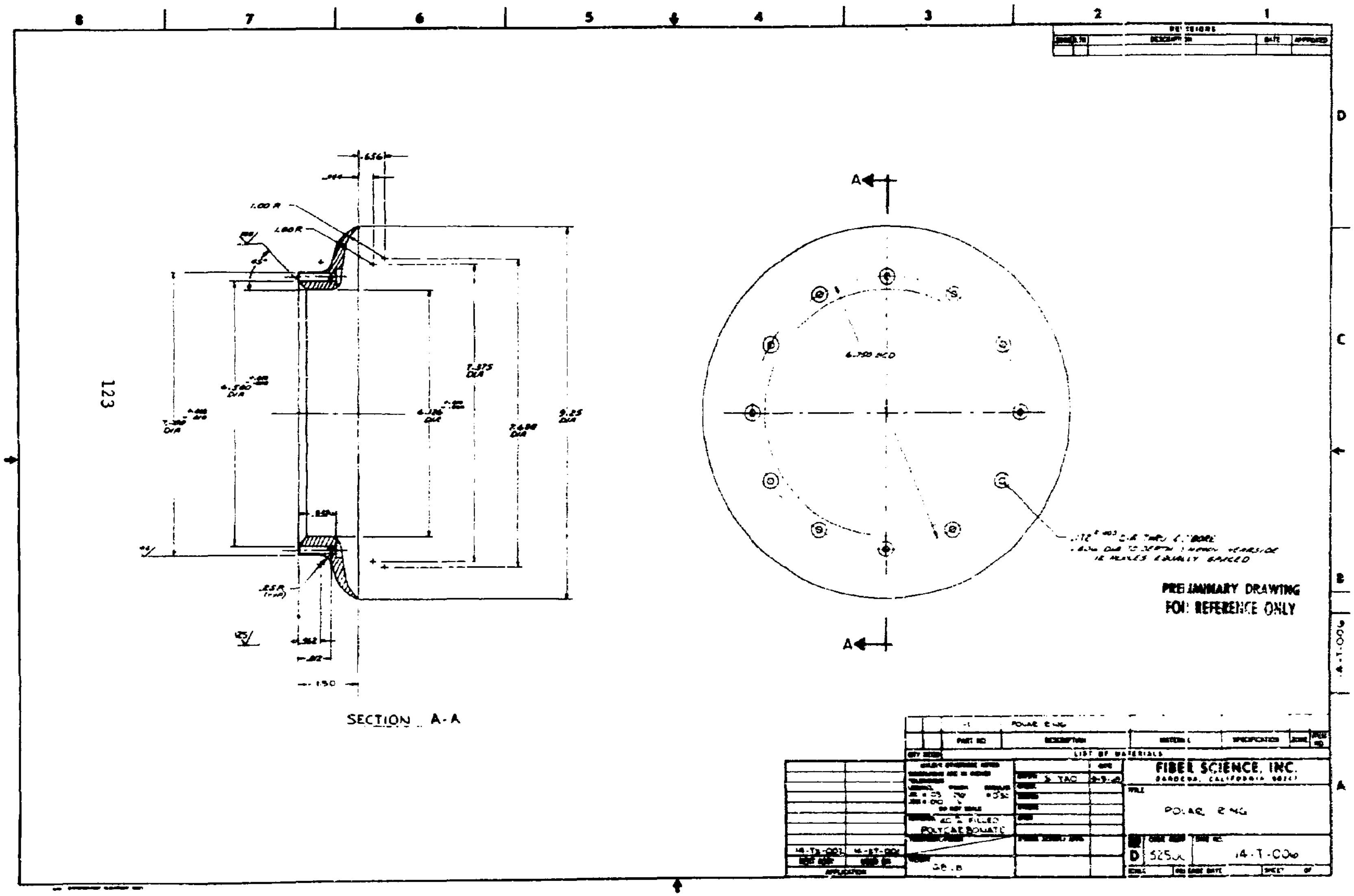


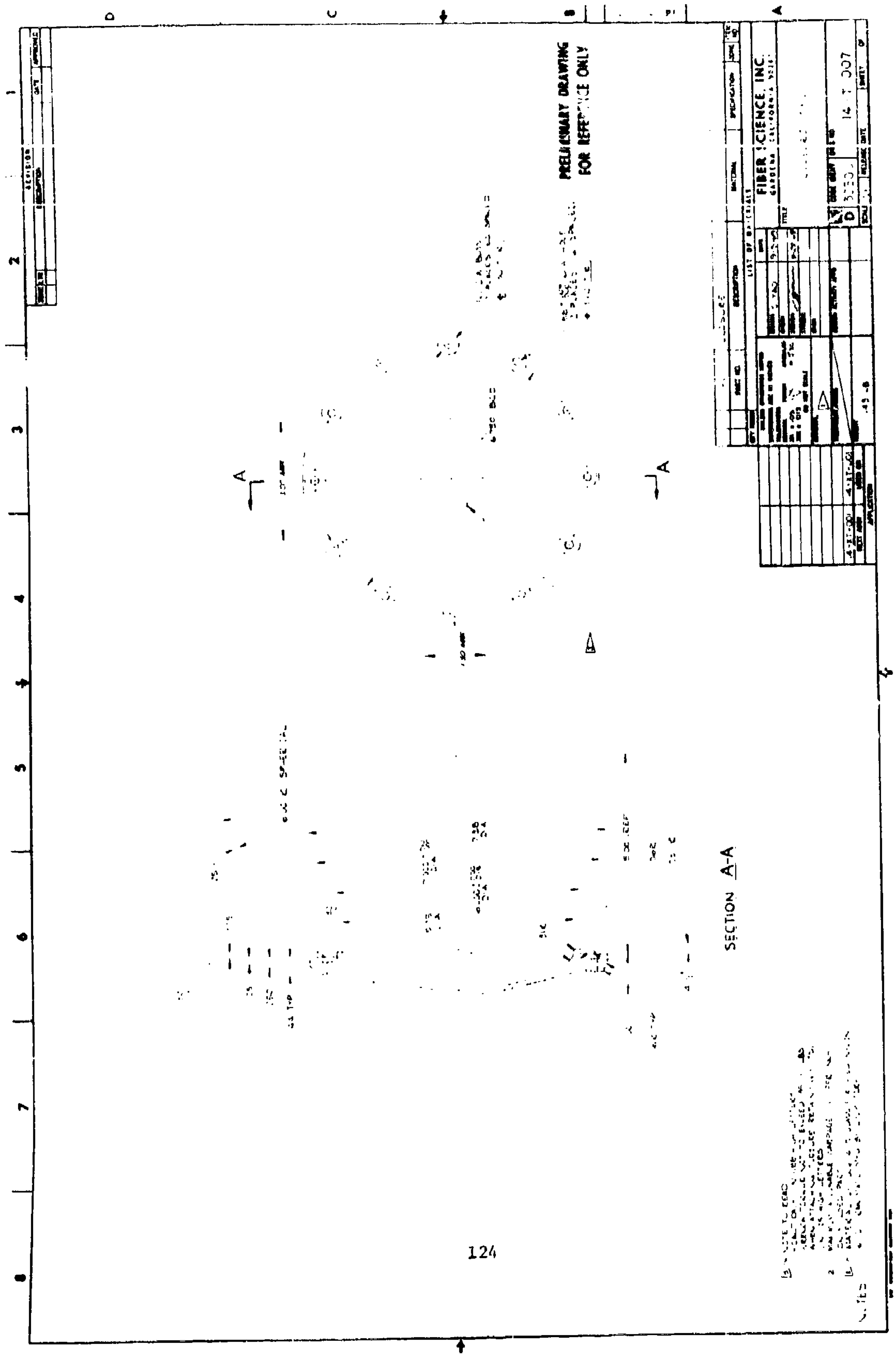
SECTION A-A
(TYPICAL)
SECTION B-B
(TYPICAL)
DETAIL C
SCALE 1/1
.150 SPHERICAL R
1.00 SPHERICAL R
9.937 DIA
17.90
14.00
PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBERGLASS CLOTH
POLYURETHANE FOAM
TAIL FOAM CLOSEOUT
LIST OF MATERIALS
FIBER SCIENCE, INC.
TAIL CONE ASSY
D
32500
14-TX-005

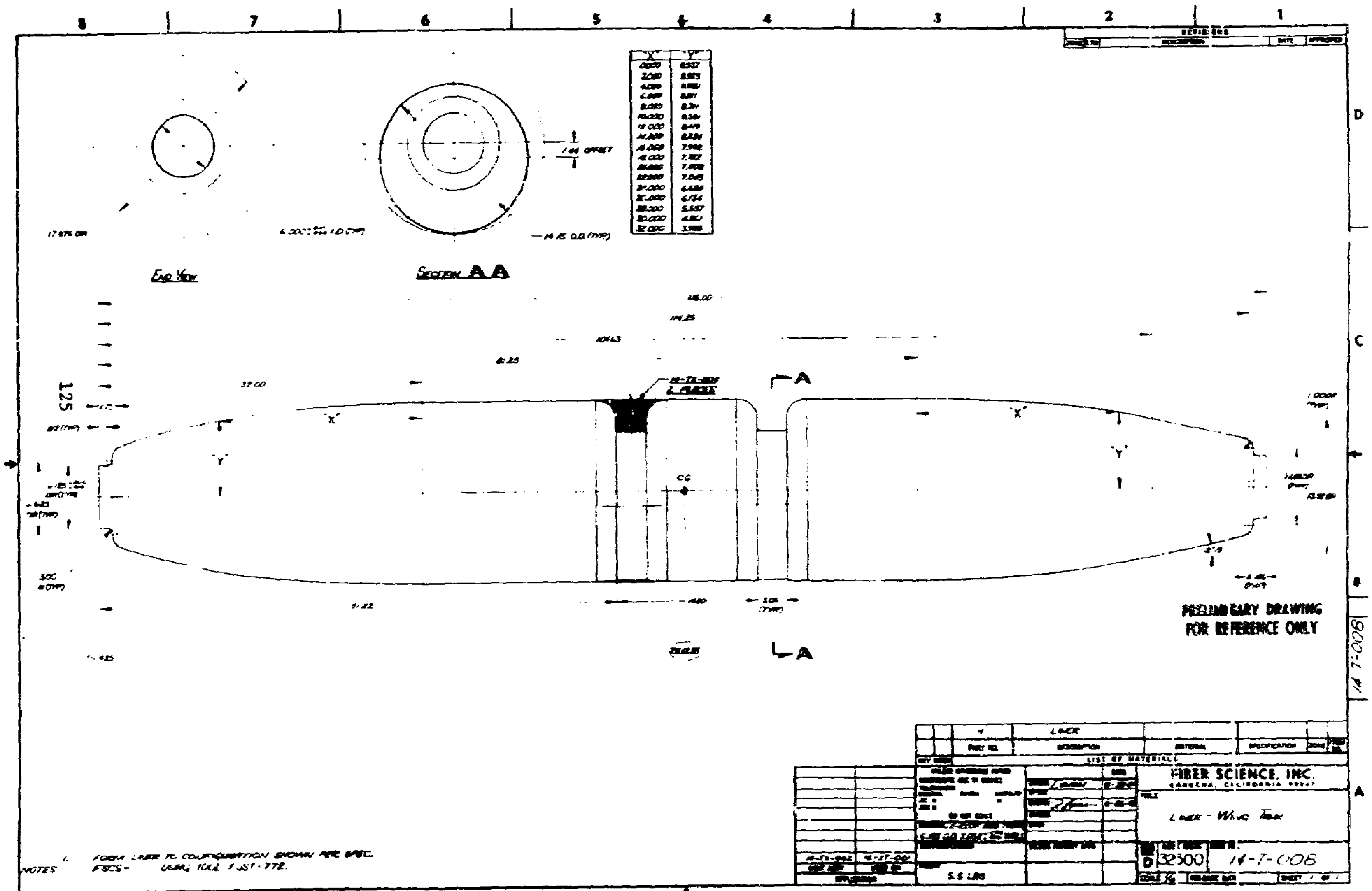

PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBER SCIENCE, INC.
SUPPORT RING ASSEMBLY
D
14-TX-004
14.75 DIA
GLASS
2.00
3.50
FOAM CORE
LIST OF MATERIALS

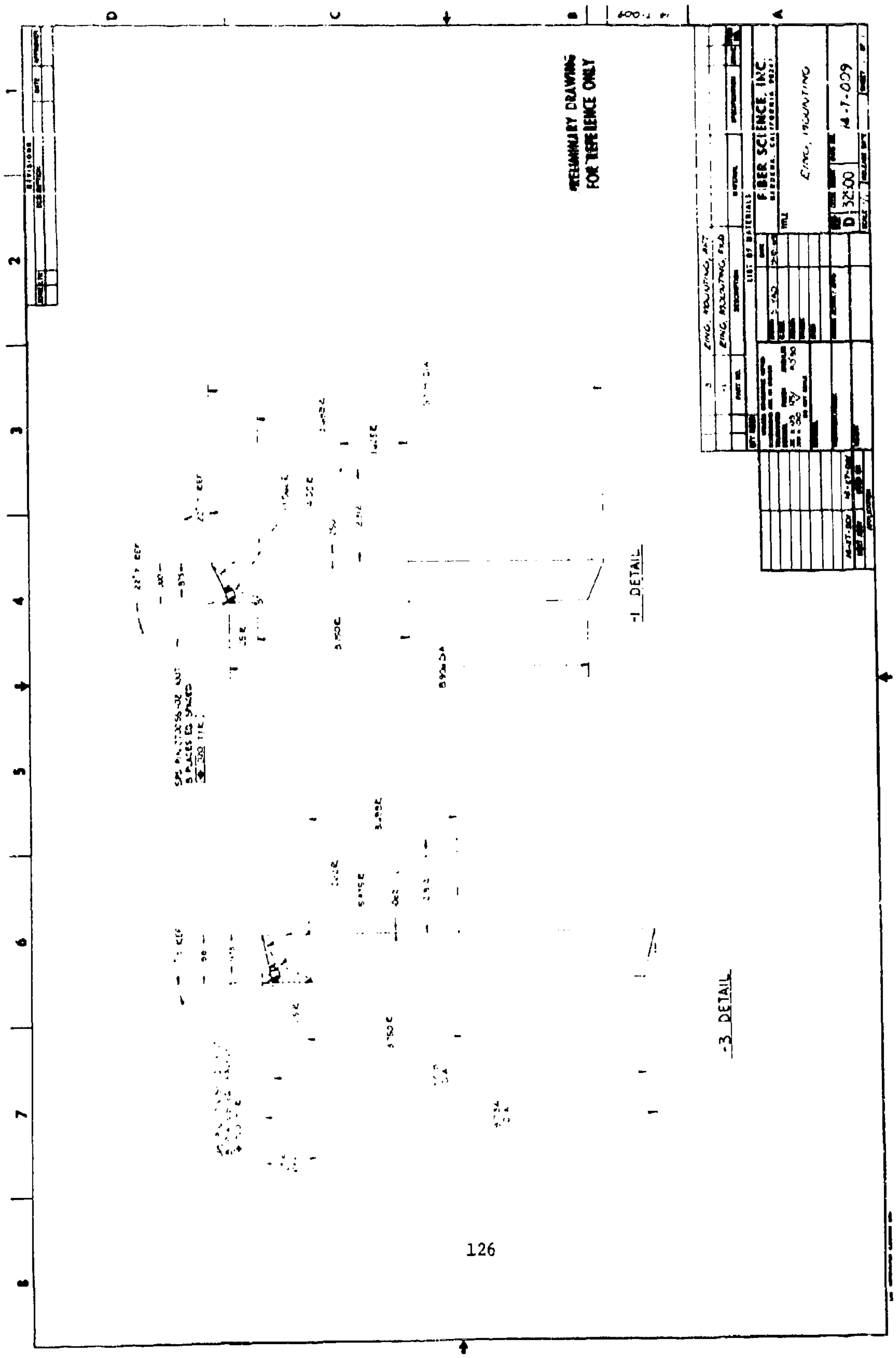


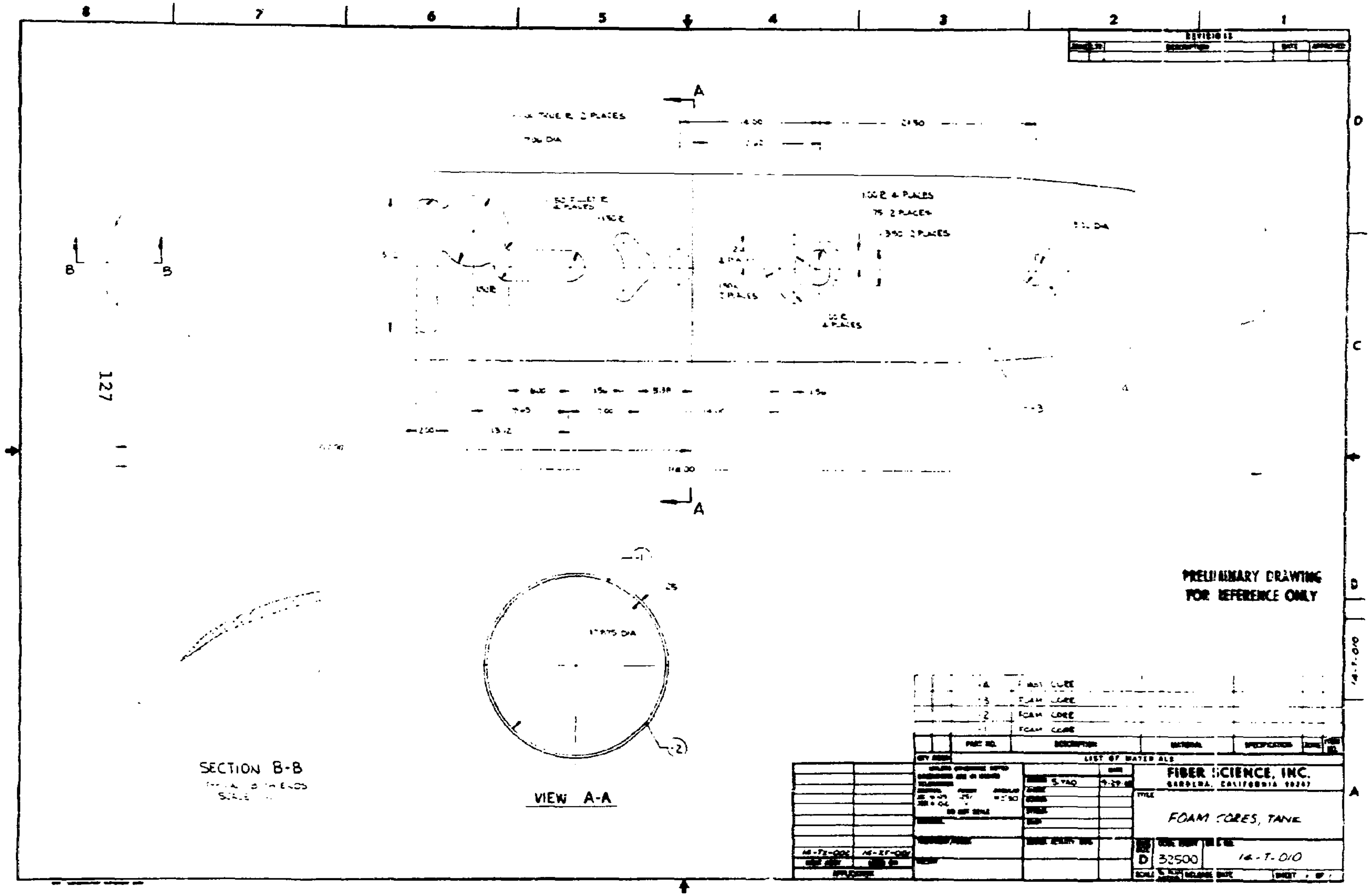
X	Y
0.000	5.000
1.000	4.579
2.000	[illegible]
3.000	[illegible]
4.000	[illegible]
5.000	[illegible]
5.500	[illegible]
5.750	[illegible]

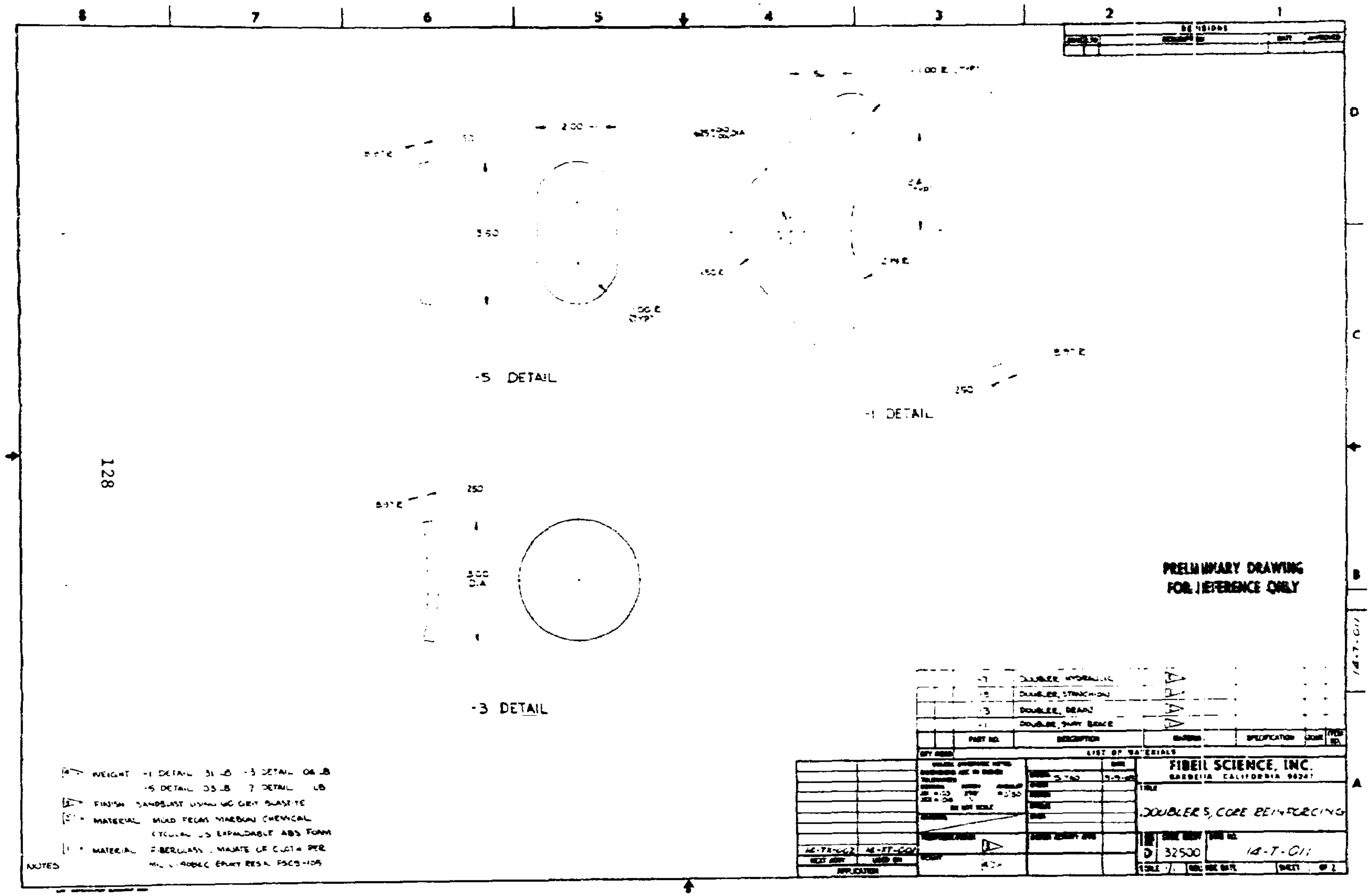

SECTION A-A
PRELIMINARY DRAWING
FOR REFERENCE ONLY
6.750 BCD
9.25 DIA
7.375 DIA
7.498 DIA
6.126 DIA
6.580 DIA
1.00 R
.656
.150
FIBER SCIENCE, INC.
POLAR RING
LIST OF MATERIALS
40% FILLED
POLYCARBONATE
14-T-006
D

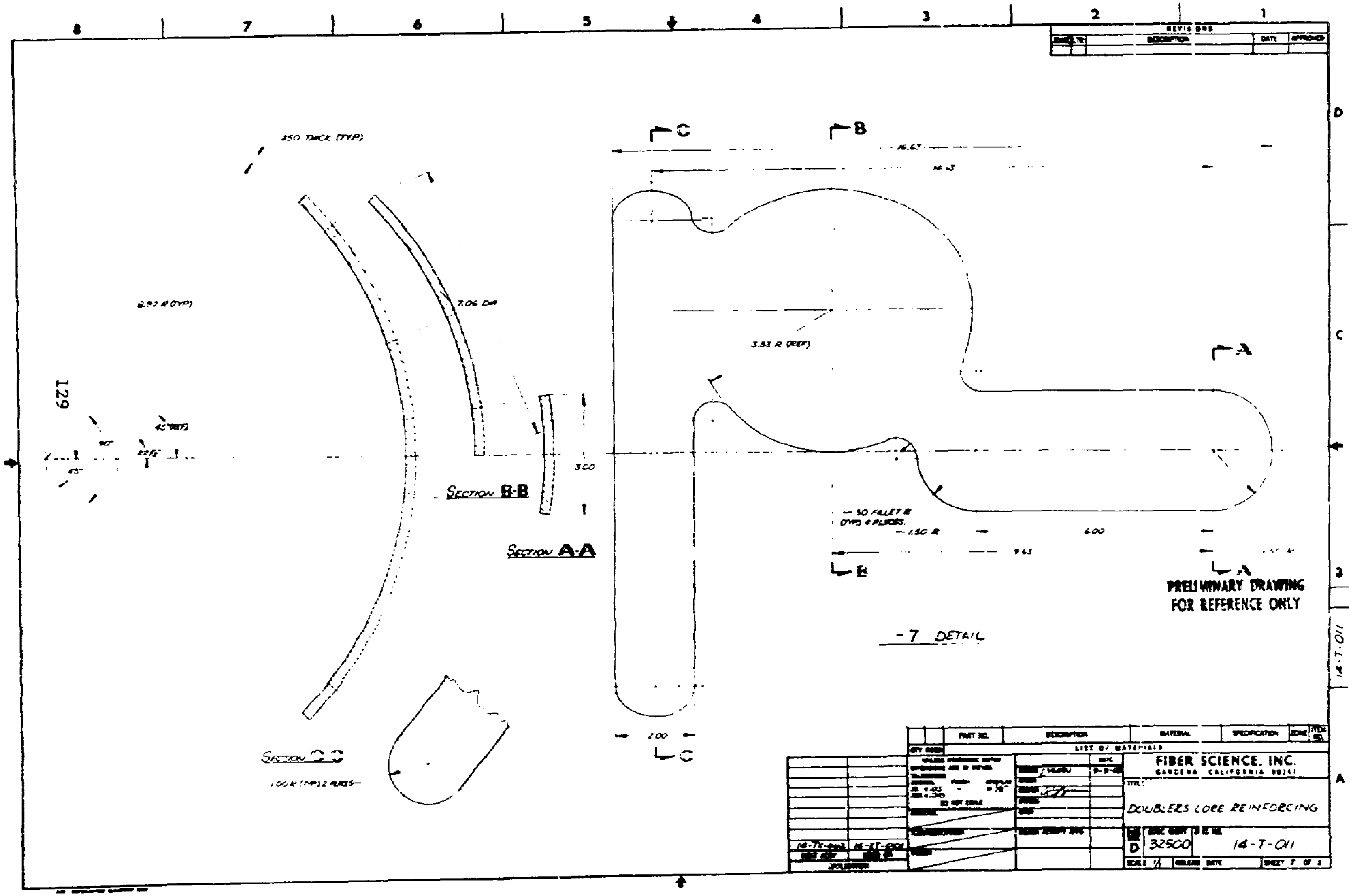

PRELIMINARY DRAWING
FOR REFERENCE ONLY
SECTION A-A
FIBER SCIENCE, INC.
14 T 307

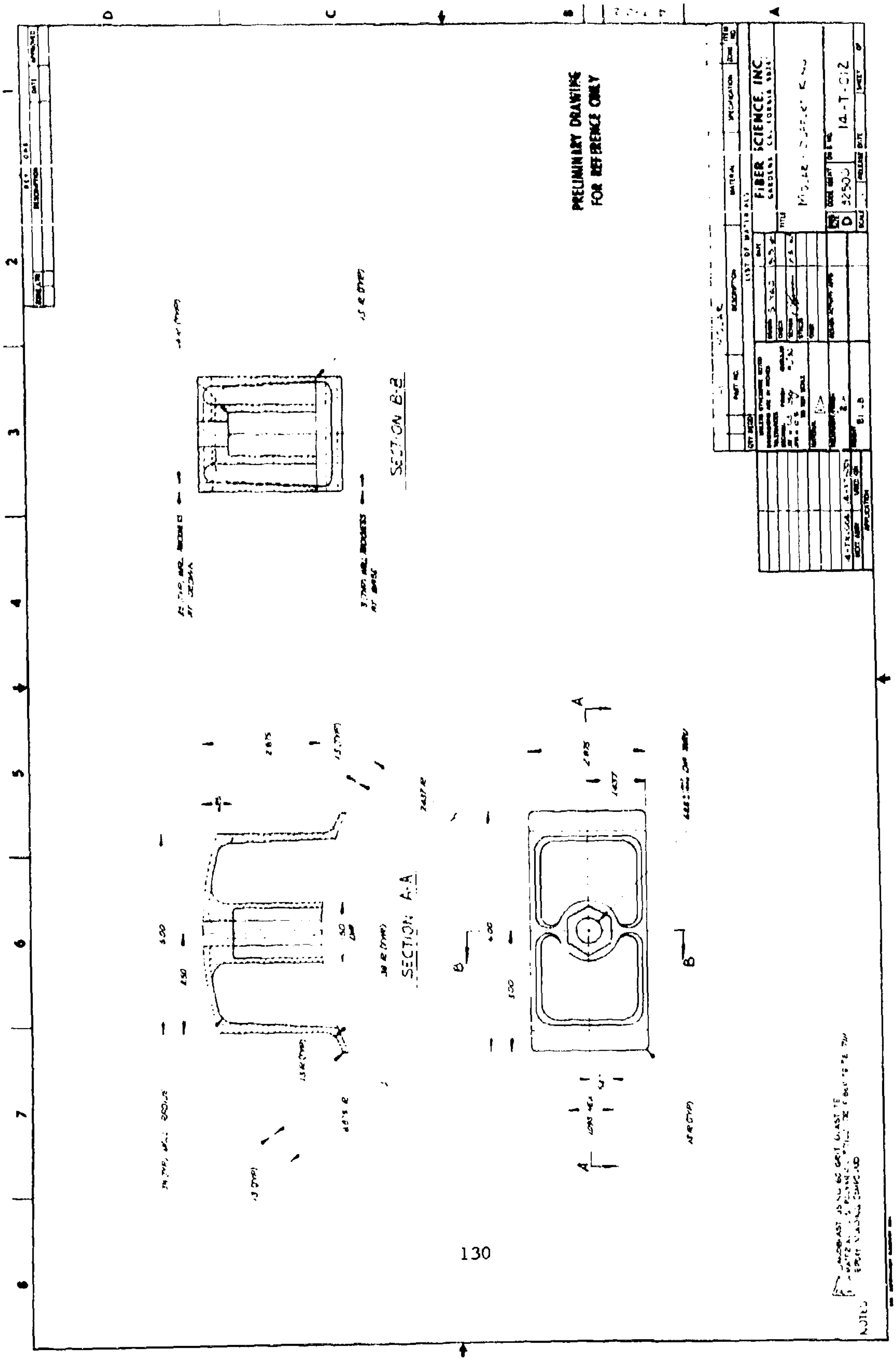

END VIEW
SECTION A A
PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBER SCIENCE, INC.
LINER - WING TANK
D 32500
14-7-008
NOTES

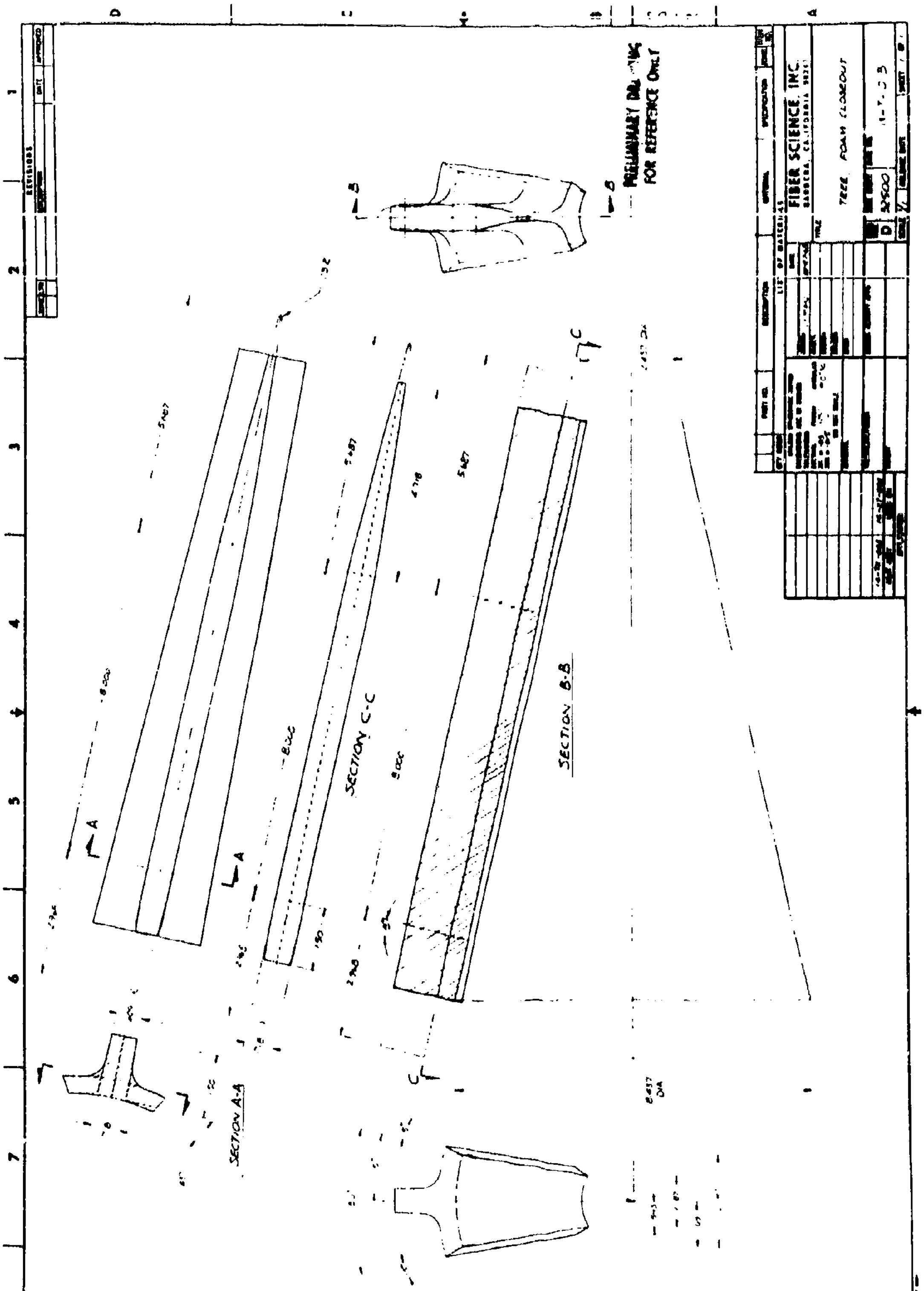

PRELIMINARY DRAWING
FOR REFERENCE ONLY
-1 DETAIL
-3 DETAIL
FIBER SCIENCE, INC.
RING, MOUNTING
14-1-009

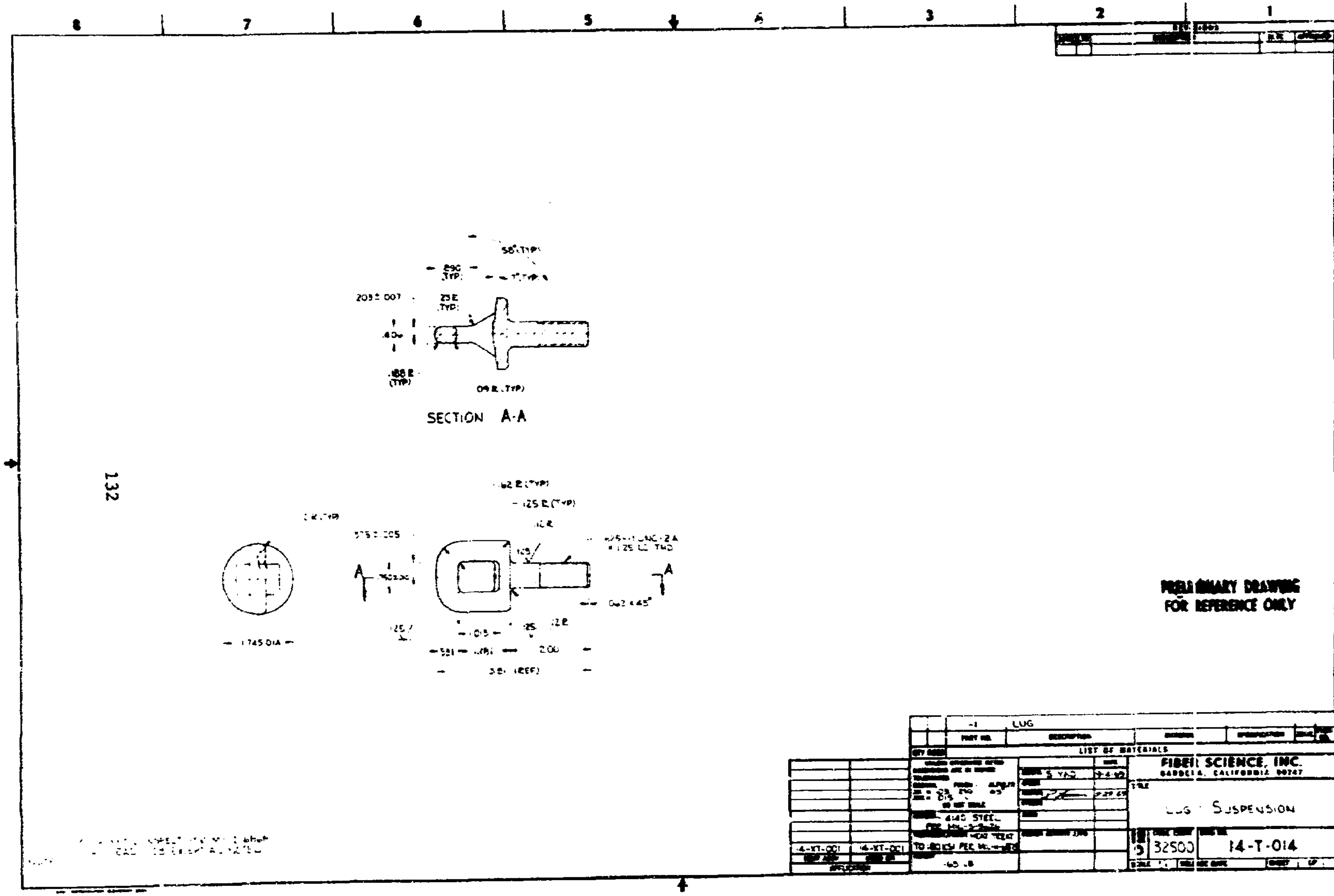

PRELIMINARY DRAWING
FOR REFERENCE ONLY
SECTION B-B
VIEW A-A
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA
FOAM CORES, TANK
D 32500
14-T-010
FOAM CORE

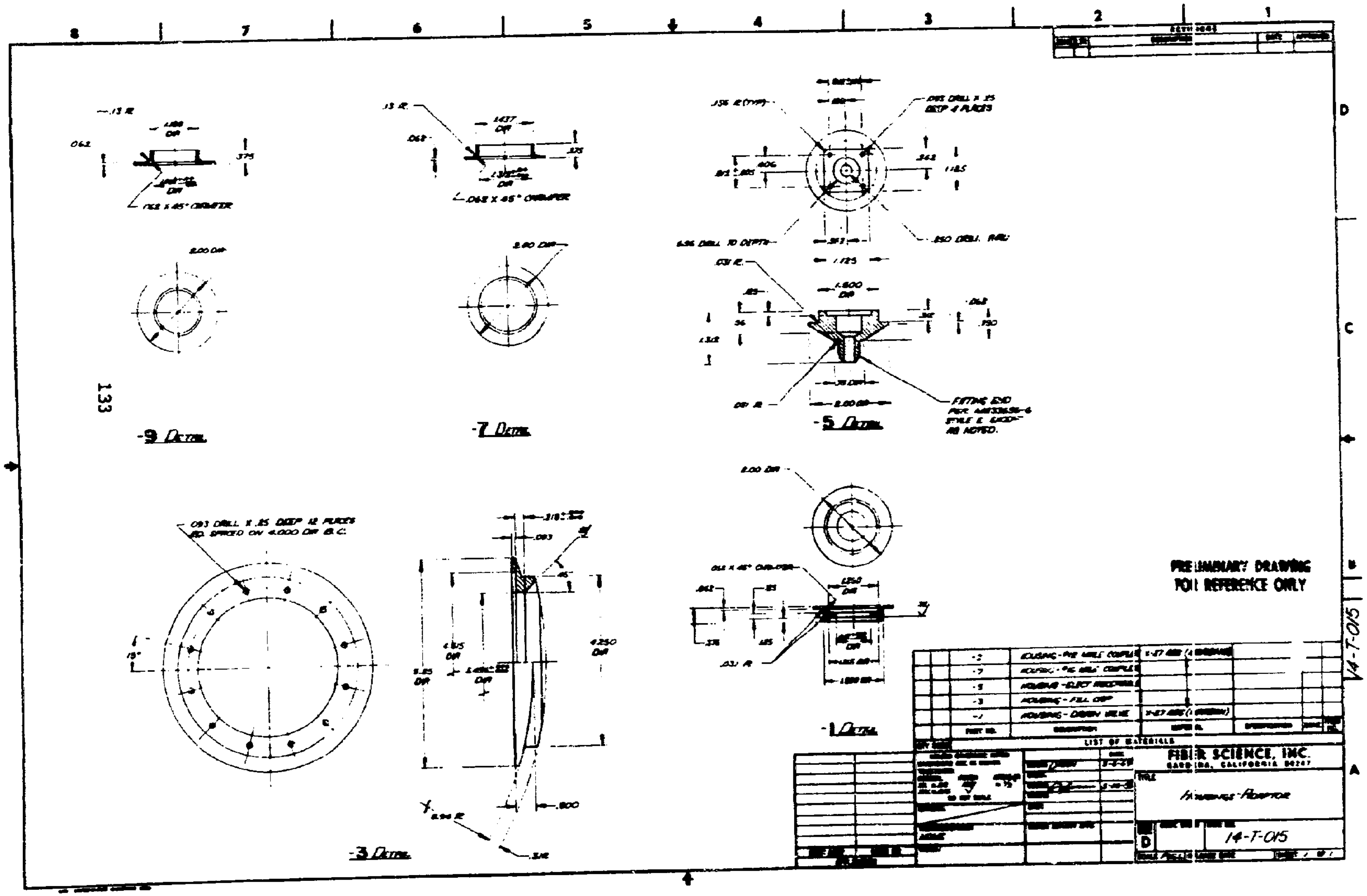

-5 DETAIL
-1 DETAIL
-3 DETAIL
PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBER SCIENCE, INC.
DOUBLERS, CORE REINFORCING
32500
14-T-011
DOUBLER, HYDRAULIC
DOUBLER, STANCHION
DOUBLER, BEAM
DOUBLER, SWAY BRACE
LIST OF MATERIALS
NOTES

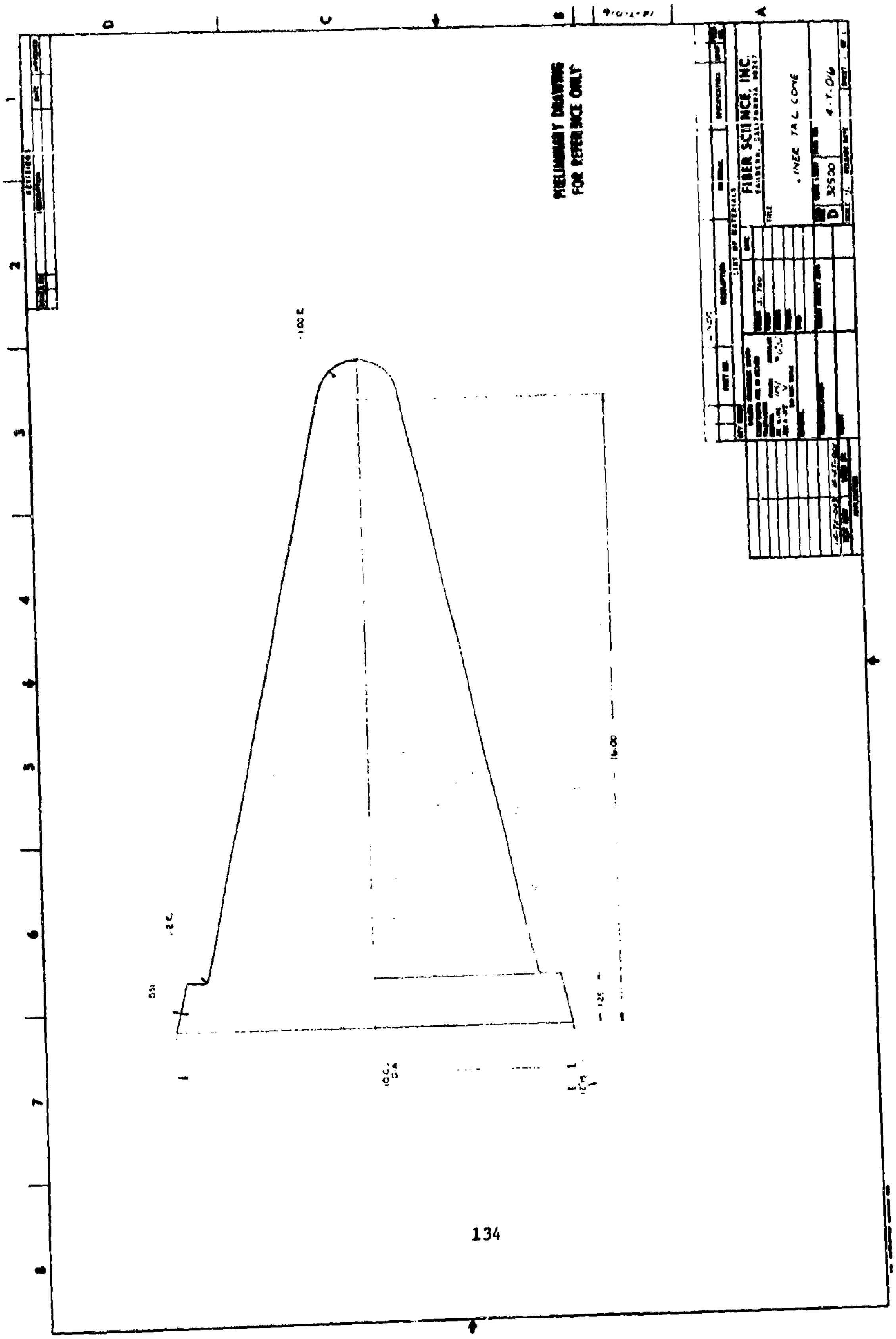

PRELIMINARY DRAWING
FOR REFERENCE ONLY
-7 DETAIL
SECTION A-A
SECTION B-B
SECTION C-C
.250 THICK (TYP)
7.06 DIA
3.53 R (REF)
.50 FILLET R
(TYP) 4 PLACES
1.50 R
6.00
9.63
16.63
14.13
2.00
3.00
1.00 R (TYP) 2 PLACES
FIBER SCIENCE, INC.
GARDENA CALIFORNIA
DOUBLERS CORE REINFORCING
D
32500
14-T-011
14-T-011

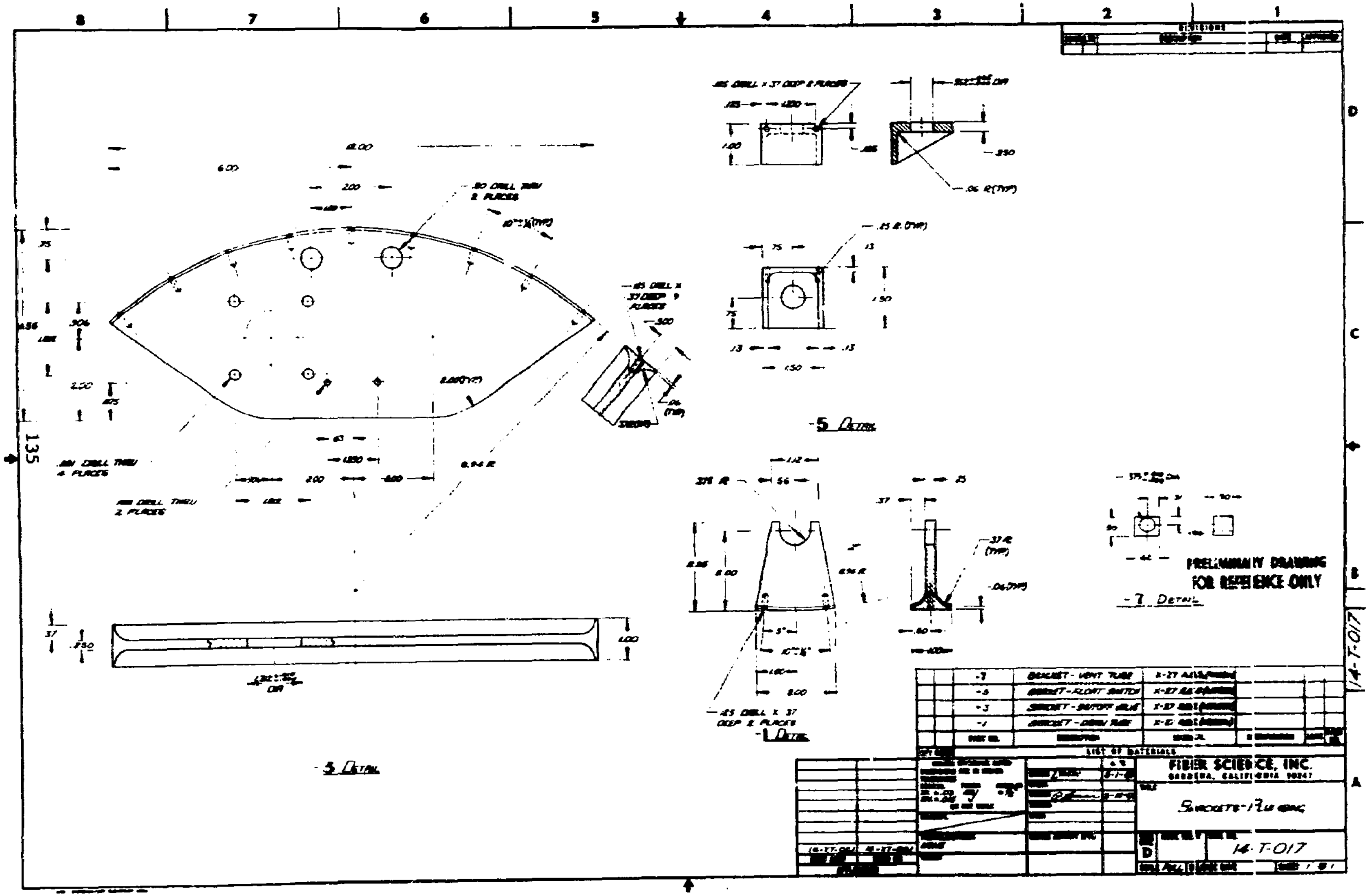

SECTION A-A
SECTION B-B
PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBER SCIENCE, INC.
D
32500
14-T-012


REVISIONS
PRELIMINARY DRAWING
FOR REFERENCE ONLY
SECTION A-A
SECTION B-B
SECTION C-C
FIBER SCIENCE INC.
TREE FOAM CLOSEOUT

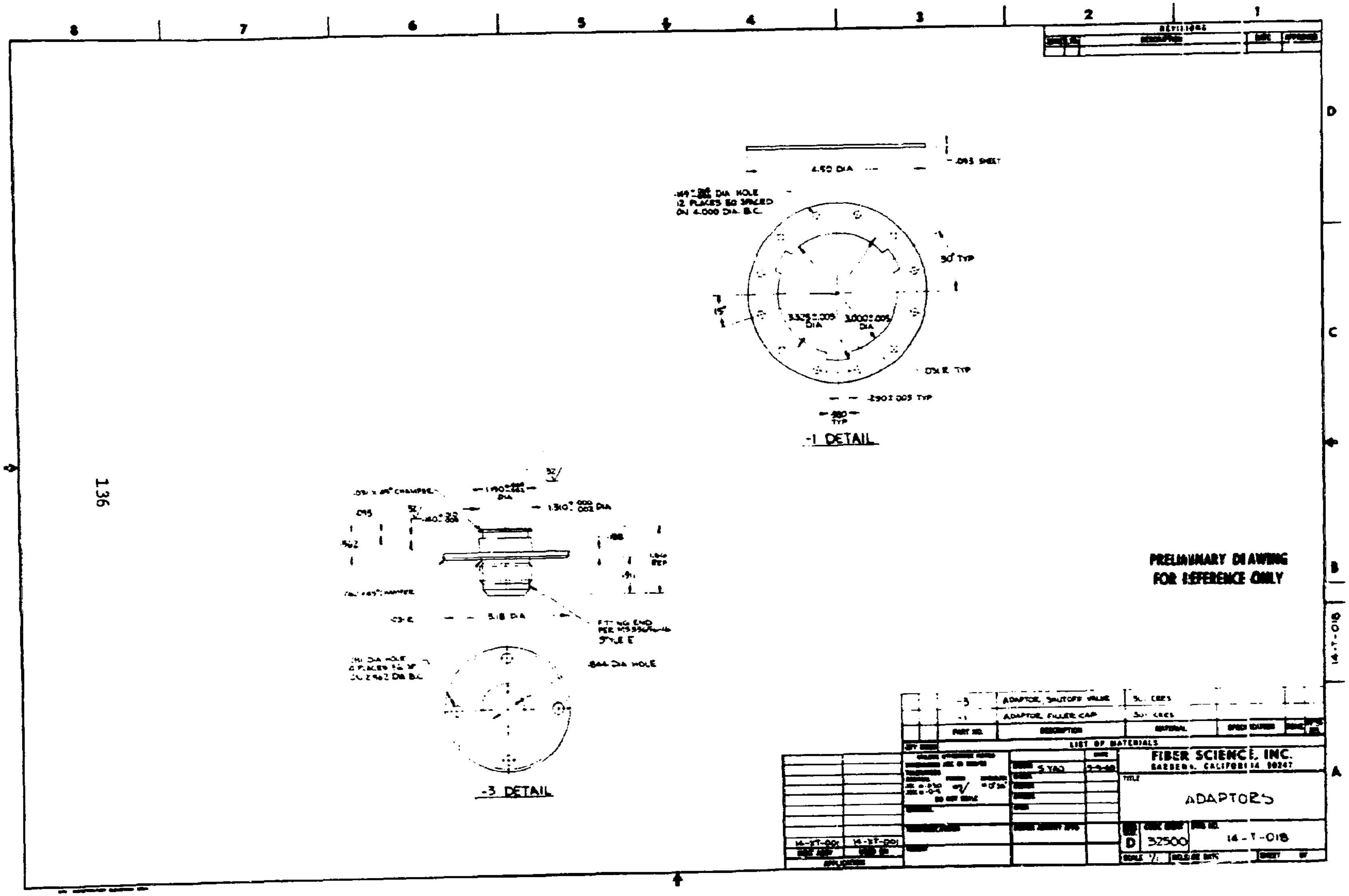

SECTION A-A
PRELIMINARY DRAWING
FOR REFERENCE ONLY
LUG
LIST OF MATERIALS
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA 90247
LUG - SUSPENSION
4140 STEEL
32500
14-T-014
14-T-04

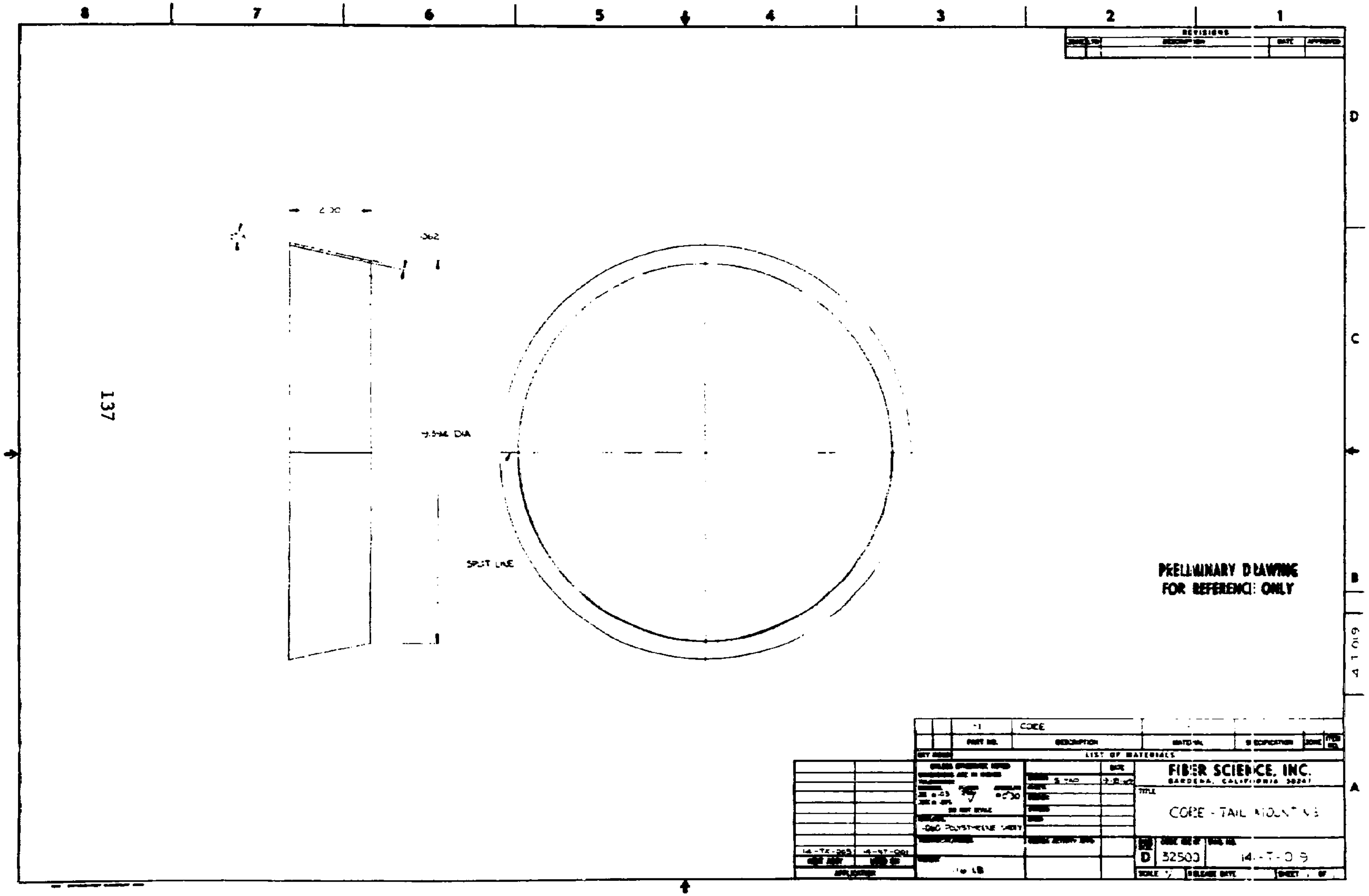

PRELIMINARY DRAWING
FOR REFERENCE ONLY
-9 DETAIL
-7 DETAIL
-5 DETAIL
-3 DETAIL
-1 DETAIL
.093 DRILL X .25 DEEP 12 PLACES
EQ. SPACED ON 4.000 DIA B.C.
FITTING END
PER. MS33656-6
STYLE E EXCEPT
AS NOTED.
HOUSING - DRAIN VALVE
HOUSING - FILL CAP
HOUSING - ELECT RECEPTACLE
LIST OF MATERIALS
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA
HOUSINGS - ADAPTOR
D
14-T-015

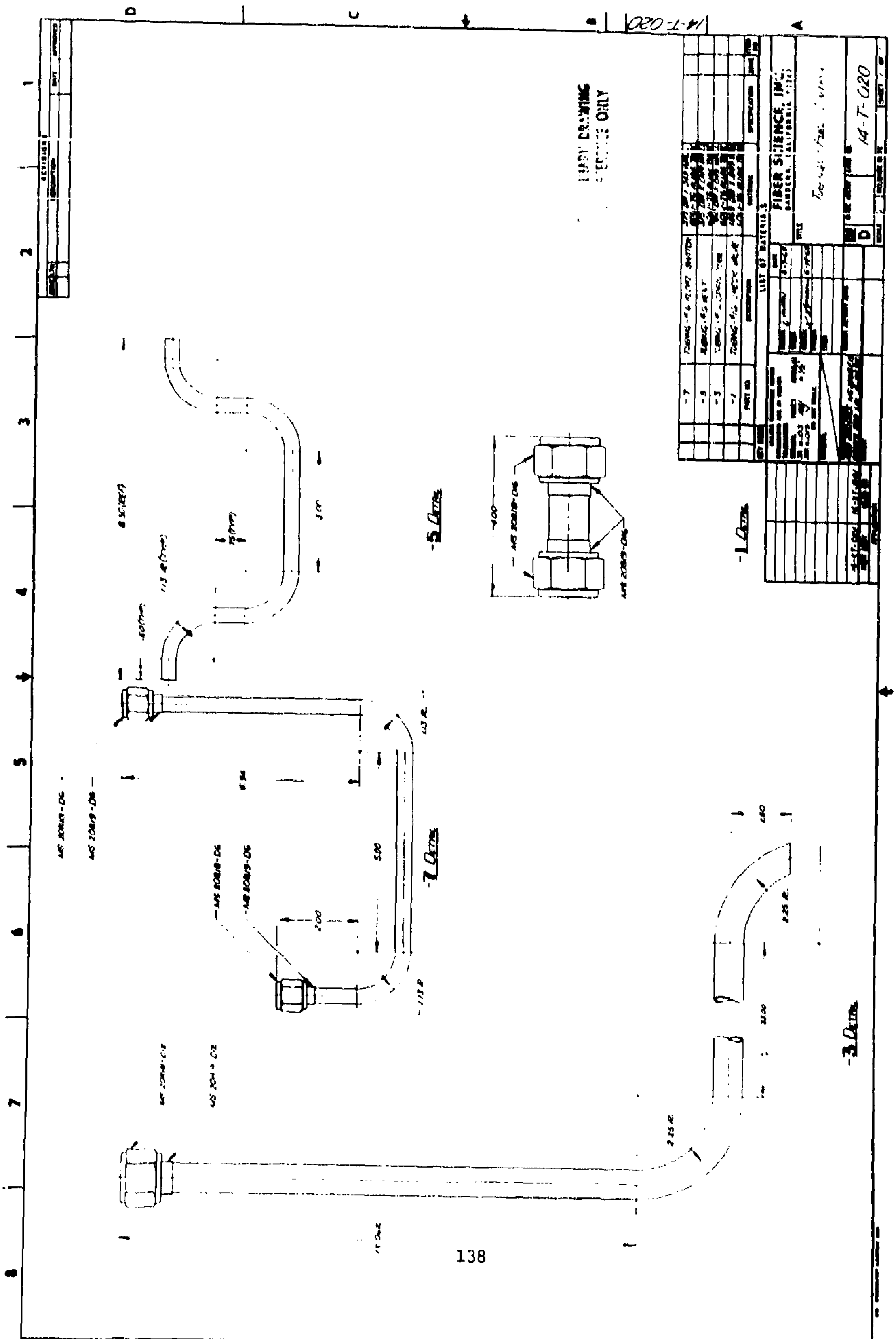

PRELIMINARY DRAWING
FOR REFERENCE ONLY
FIBER SCIENCE, INC.

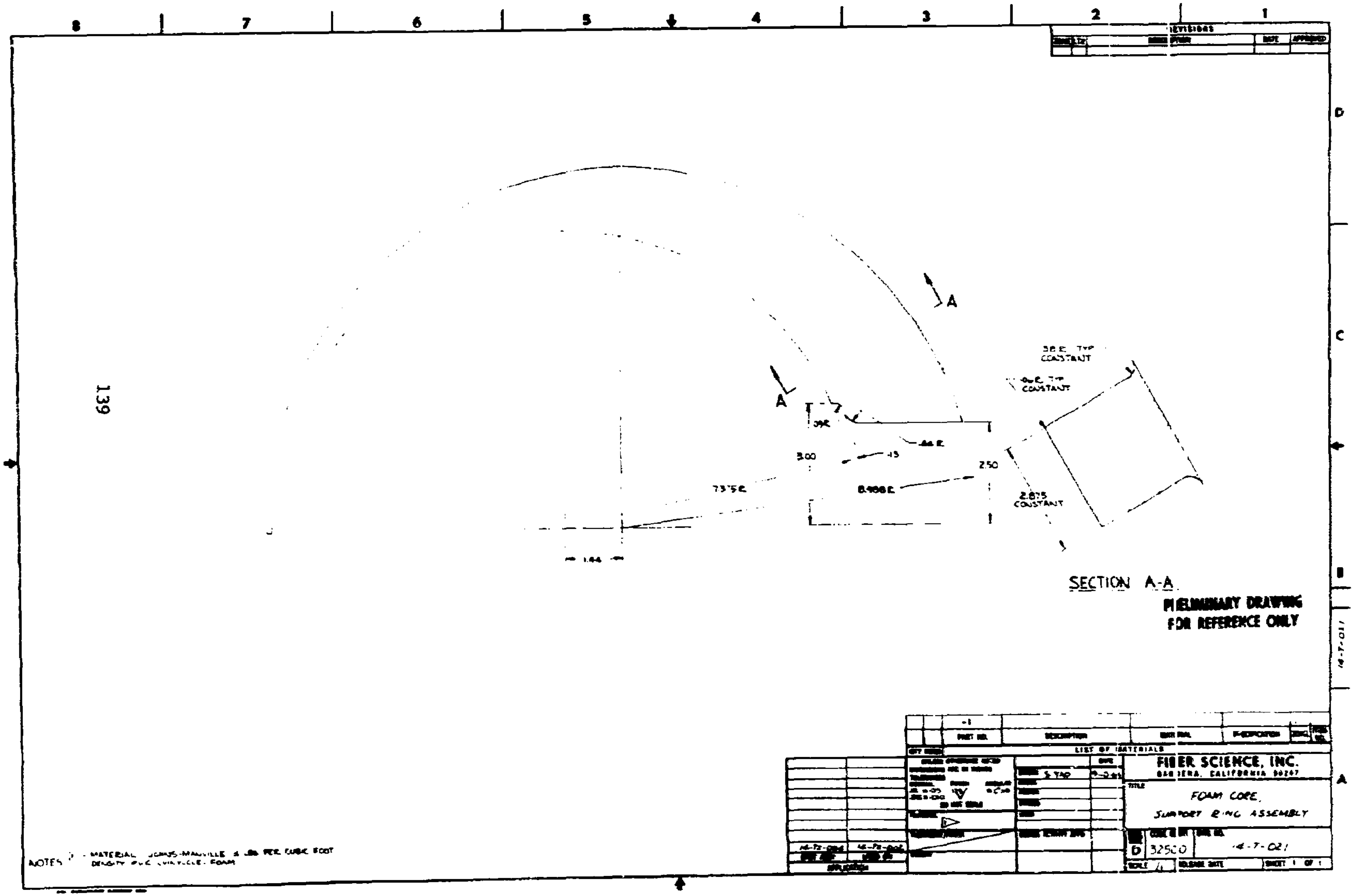


PRELIMINARY DRAWING
FOR REFERENCE ONLY
-5 DETAIL
-1 DETAIL
-7 DETAIL
-3 DETAIL
-7 BRACKET - VENT TUBE
-5 BRACKET - FLOAT SWITCH
-3 BRACKET - SHUTOFF VALVE
-1 BRACKET - DRAIN TUBE
LIST OF MATERIALS
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA 90247
14-T-017


PRELIMINARY DRAWING
FOR REFERENCE ONLY
4.50 DIA
.093 SHEET
12 PLACES EQ SPACED
ON 4.000 DIA. B.C.
30° TYP
15°
DIA
-1 DETAIL
1.310 DIA
5.18 DIA
FITTING END
STYLE E
.844 DIA HOLE
-3 DETAIL
ADAPTOR, SHUTOFF VALVE
ADAPTOR, FILLER CAP
LIST OF MATERIALS
FIBER SCIENCE, INC.
ADAPTORS
D
32500
14-T-018


PRELIMINARY DRAWING
FOR REFERENCE ONLY
SPLIT LINE
DIA
CORE
LIST OF MATERIALS
FIBER SCIENCE, INC.
CORE - TAIL
D
32500


FIBER SCIENCE, INC.
14-T-020
LIST OF MATERIALS
-1 Detail
-3 Detail
-5 Detail
-7 Detail


SECTION A-A
PRELIMINARY DRAWING
FOR REFERENCE ONLY
.38 R. TYP CONSTANT
.06 R. TYP CONSTANT
2.875 CONSTANT
8.988 R
73.5 R
3.00
2.50
.44 R
1.44
FIBER SCIENCE, INC.
GARDENA, CALIFORNIA 90247
FOAM CORE,
SUPPORT RING ASSEMBLY
LIST OF MATERIALS
D 32500
14-7-021
NOTES: 1. MATERIAL: JOHNS-MANVILLE 4 LBS PER CUBIC FOOT DENSITY PVC (VINYLCEL) FOAM

APPENDIX II

MATERIAL PROPERTIES

The properties of the glass filaments and epoxy resin matrix are shown in Table X.

TABLE X

GLASS FILAMENTS AND EPOXY RESIN PROPERTIES

PROPERTY	E-HTS GLASS	EPOXY RESIN
F_{tu}, psi	325,000	10,500
E , 10^6 psi	10.5	0.5
ψ , 10^{-6} in/in/^{o}F	2.8	32.0
μ	0.22	0.35
ρ , lbs/in^3	0.0917	0.0444

The properties of a unidirectional glass and resin composite with 28% resin by weight are calculated as follows:

$$V_r = \frac{W_r \rho_g}{\rho_r - W_r(\rho_r - \rho_g)} \qquad \text{(resin volume fraction)}$$

$$V_r = \frac{.28 \times .0917}{.0444 - .28\ (.0444 - .0917)} = .445$$

The composite glass and resin density "ρ_c" is:

$$\rho_c = V_r \rho_r + (1 - V_r)\rho_g$$

$$\rho_c = .455 \times .0444 + (1 - .445).0917 = .071 \text{ lbs/in}^3$$

The composite unidirectional modulus and tensile strength parallel to the fiber orientation are:

$$E_{//} = E_g(1-V_r) + E_r(V_r)$$

$$E_{//} = \left[10.5(1-.445) + 0.5\ (.445)\right] 10^6 = 6.04 \times 10^6 \text{ psi}$$

$$F_{//} = F_g(1-V_r) + F_r(V_r)$$

$$F_{//} = 325{,}000(1-.445) + 10{,}500(.445) = 184{,}600 \text{ psi}$$

The composite unidirectional modulus and tensile strength normal to the fiber orientation are estimated to be:

$$E_{\perp} = 1.5 \times 10^6 \text{ psi}$$

$$F_{\perp} = 2{,}000 \text{ psi}$$

The composite unidirectional compressive properties are assumed equal to the tensile properties. This assumption is very good for the properties parallel to the fibers and conservative for the properties normal to the fiber orientation.

The thickness per ply (one layer is equal to two plies) of filament windings is a function of the band density (number ends/inch) and the resin fraction. This tank was wound with a band density of approximately 125 ends/inch and 28% resin by weight ($V_r = .445$). The ply thickness is calculated as follows:

$$t_{ply} = \frac{A_g \times B.D.}{1 - V_r}$$

$$t_{ply} = \frac{20.76 \times 10^{-6} \times 125}{1 - .445} = .00467 \text{ in.}$$

Tables XI and XII show the properties for style 181 E glass fabric/epoxy and other materials used.

TABLE XI

EPOXY LAMINATE PROPERTIES
Reinforced with 181 style E glass fabric

PROPERTY	FIBER ORIENTATION		
	0°	45°	90°
F_{tu} , psi	50,000	20,000	47,000
F_{cu} , psi	48,000	26,000	44,000
F_{su} , psi	13,000	20,000	13,000
F_{sui}, psi	3,000	2,800	2,400
E , 10^6 psi	3.0	1.5	2.5
G , 10^6 psi	0.8	1.5	0.8
ρ ,	0.069		
W_r , %	30.0		
V_r , %	47.0		

TABLE XII

MISCELLANEOUS MATERIAL PROPERTIES

MATERIAL	STRENGTH (PSF)				MODULUS-PSI		DENSITY #/IN³
	F_{tu}	F_{cu}	F_{su}	F_{bru}	ELASTICITY	RIGIDITY	
Urethane Foam 6#/ft³	--	200	140	--	5,000	--	.00348
PVC Foam 4#/ft³	--	150	125	--	6,000	2,000	.00231
Polycarbonate Molding Compound 40% Glass Filled	18,000	18,500	8,000	27,000	1.2×10^6	--	.0548
Cycolac JP (X63) ABS Foam	2,400	--	--	--	90,000	--	.0181
EM 7102 Epoxy Molding Compound	25,000	37,000	12,000	--	--	--	.0678

APPENDIX III

SPECIFICATIONS

Issued 11-4-68 Revised Revised Revised Revised	FIBER SCIENCE CONTROL SPECIFICATION FSCS-102 EPOXY RESIN MIXING

1. APPLICATION: Primarily used as the resin system in the fabrication of flame retardant filament wound high strength vessels.

2. FORMULATION:

2.1 Composition: The resin system shall be formulated as follows:

Resin Components	
Dow DER	50 parts by weight
Ciba RD4	15 parts by weight
Ciba 6004	35 parts by weight
	100 parts by weight

Hardener Components	
U.S. Royal Tonox	27 parts by weight
Harshaw BF_3MEA	1 part by weight
	28 parts by weight

2.2 Blending: The resin system shall be blended as follows:

2.2.1 Preheat Dow DER 542 resin to liquid state (approx. 200°F).

2.2.2 Preheat Tonox hardener to liquid state (approx. 150°F).

2.2.3 Determine batch size and weigh out proper proportions.

2.2.4 Mix warm Dow DER 542 with Ciba 6004 until all resin is uniform consistency.

2.2.5 Mix measured amount of Ciba RD4 with blend until all resin is uniform consistency. Cool blend to 90°F ± 15°F.

2.2.6 Mix thoroughly measured amounts of BF_3MEA with warm Tonox.

2.2.7 Cool hardener blend to 90°F ± 10°F. Use blend within four hours to avoid crystallization. May be reheated, if required.

2.2.8 Mix resin blend and hardener only when needed. Mix thoroughly for minimum of 30 seconds.

3. INSPECTION: Inspect resin prior to use for lumps, color, mixing, temperature (maximum 110°F). Discard mixed resin after three hours, if not used.

4. POT LIFE: Pot life in 500 gm. batches is two hours. Use extreme caution to prevent larger batches from exceeding material pot life.

5. CAUTION: Epoxy chemicals can be irritants. Use care in handling all materials. Do not breathe fumes. Avoid contact with skin.

6. CURING: Cure epoxy resin blend per either of the following:

a. Gel at 175°F for two hours. Cure at 250°F for six hours.

b. Gel at 175°F for two hours. Cure at 300°F for four hours.

7. APPROVED SOURCES:

Dow DER 542, a product of the Dow Chemical Company, Midland, Michigan, Los Angeles distributor Thalco, 7431 Flotilla.

Ciba RD4 and Ciba 6004, products of Ciba Products Company, Summit, New Jersey, Los Angeles distributor, Dorsett & Jackson, 3800 Noakes Street.

U. S. Royal Tonox, a product of Naugatuck Chemical Division, U.S. Rubber Corporation, Los Angeles distributor, Uniroyal Chemicals, 5901 Telegraph Road, City of Commerce, California.

Harshaw BF_3MEA, a product of the Harshaw Chemical Company, Cleveland, Ohio, Los Angeles distributor, Harshaw Chemical Company, 6500 East Washington Boulevard, City of Commerce, California.

Issued 9-9-69 Revised Revised Revised Revised	FIBER SCIENCE CONTROL SPECIFICATION FSCS-106 EPOXY RESIN MIXING

1. APPLICATION: Primarily used as the resin system in the fabrication of flame retardant filament wound high strength vessels.

2. FORMULATION:

2.1 Composition: The resin system shall be formulated as follows:

Resin Components	
Dow DER 542	60 parts by weight
ERR 4205	40 parts by weight
	100 parts by weight
Hardener Components	
U.S. Royal Tonox	82 parts by weight/100
DMP-30	2 parts by weight/100
	84 parts by weight/100

2.2 Blending: The resin system shall be blended as follows:

2.2.1 Preheat Dow DER 542 resin to liquid state (approx. 200°F).

2.2.2 Preheat Tonox hardener to liquid state (approx. 150°F).

2.2.3 Determine batch size and weigh out proper proportions of resin and hardener.

2.2.4 Mix warm Dow DER 542 with ERR 4205 until all resin is uniform consistency. Cool final blend to 125 ± 15°F.

2.2.5 Mix thoroughly measured amounts of DMP-30 with warm Tonox.

2.2.6 Cool hardener blend to 90°F ± 10°F. Use blend within four hours to avoid crystallization. May be reheated, if required.

2.2.7 Mix resin blend and hardener only when needed. Mix thoroughly for minimum of 60 seconds. Scrape container walls thoroughly.

3. INSPECTION: Inspect resin prior to use for lumps, color, mixing, temperature (maximum 110°F). Discard mixed resin after three hours, if not used.

4. POT LIFE: Pot life in 500 gm. batches is eight hours. Use extreme caution to prevent larger batches from exceeding material pot life.

5. CAUTION: Epoxy chemicals can be irritants. Use care in handling all materials. Do not breathe fumes. Avoid contact with skin.

6. CURING: Cure epoxy resin blend per either of the following:

a. Gel at 175°F for two hours. Cure at 250°F for six hours.

b. Gel at 175°F for two hours. Cure at 300°F for four hours.

7. APPROVED SOURCES:

Dow DER 542, a product of the Dow Chemical Company, Midland, Michigan, Los Angeles distributor Thalco, 7431 Flotilla.

ERR 4205, a product of Union Carbide, New York, N.Y., Los Angeles sales office at 2770 Leonix Boulevard.

U.S. Royal Tonox, a product of Naugatuck Chemical Division, U.S. Rubber Corporation, Los Angeles distributor, Uniroyal Chemicals, 5901 Telegraph Road, City of Commerce, California.

DMP-30, a product of the Rohm and Haas Company, Philadelphia, Pennsylvania, Los Angeles distributor, Rohm and Haas Company, 1920 South Tube Way.

Issued 9-22-69 Revised Revised Revised Revised	FIBER SCIENCE CONTROL SPECIFICATION FSCS-146 FIBERGLASS ROVING (FERRO S-1014)

1. APPLICATION: Primarily used as the reinforcing fibers of filament wound high strength vessels.

2. PRODUCT FORM: Continuous strand zero twist glass fibers supplied as 9-end roving on a center pull package.

3. FINISH: Epoxy compatible (Ferro S-24).

4. TYPICAL PROPERTIES:

   Tensile Strength = 325,000 psi

   Modulus of Elasticity = 12.4×10^6 psi

   Coefficient of Thermal Expansion =

   Density = 0.090 lbs/in^3

5. APPROVED SOURCE:

   Ferro Corporation, 18811 Fiber Glass Road, Huntington Beach, California.

Issued 9-22-69 Revised Revised Revised Revised	FIBER SCIENCE CONTROL SPECIFICATION FSCS-145 FIBERGLASS ROVING (AEROROVE ® 3)

1. APPLICATION: Primarily used as the reinforcing fibers of filament wound high strength vessels.
2. PRODUCT FORM: Continuous strand, zero twist, glass fibers supplied as single end roving on a cake package.
3. FINISH: Epoxy compatible.
4. TYPICAL PROPERTIES:

   Tensile Strength = 325,000 psi *

   Modulus of Elasticity = 13.5×10^6 psi

   Coefficient of Thermal Expansion = $2.32 \times 10^{-6}/^{o}F$.

   Density = 0.090 lbs/in^3
5. APPROVED SOURCE:

   Glass Fiber Products, Inc., 6230 Irwindale Avenue, Azusa, California.

REFERENCES

1. Khoury, M. S. and R. L. Trissell, Model A-37B Wing Pylon Loads, Cessna Aircraft Company Report No. 318E-6704-053, Air Force Contract No. F33657-67-C-0824, September 1967.

2. Abildskov, D. P. and J. Daines, Investigation of Advanced Design Concepts for Deep Submersibles, Hitco Final Report, Buships Project No. R-007-03-04, Task 1008, Contract No. NObs-90180, February 1965.

3. Krenzke, M. A. and R. M. Charles, The Elastic Buckling Strength of Spherical Glass Shells, David Taylor Model Basin Report No. 1759, September 1963.

4. Peery, D. J., Aircraft Structures, New York: McGraw-Hill Book Company, Inc., 1950.

5. Zophres, W. C., Buckling of Sandwich Cylinders and Cones, Zenith Aircraft Report No. SSR-2, July 1956.

6. Myers, N. C., G. D. Lee, F. C. Wright, and J. Daines, Investigation of Structural Problems with Filament Wound Deep Submersibles, Hitco Final Report, Buships Project No. S-F013-05-03, Task 1025, Contract No. NObs-88351, January 1964.

7. Daines, J., Test Procedure QTPA-100 for the Cessna A-37B Aircraft One Hundred Gallon External Fuel Tank, Fiber Science, Inc., November 1968.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) FIBER SCIENCE, INC. 245 East 157th Street Cardena, California 90247	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

FILAMENT WOUND FIBER GLASS WING TANK

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report, July 1968 through August 1969

5. AUTHOR(S) (First name, middle initial, last name)

Abildskov, Dale P.
Ashton, Larry J.
Lyman, Richard R.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	150	Seven (7)

8a. CONTRACT OR GRANT NO. F33615-68-C-1622 new b. PROJECT NO. 1559 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TRA-100 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFML-TR-70-4

10. DISTRIBUTION STATEMENT

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	AFML Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

Ten (10) filament wound glass reinforced plastic, sandwich-wall wing tanks were fabricated using a process amenable to low cost production. The tanks were 100-gallon capacity and designed to meet the Cessna A-37B wing tank geometry and loading excepting for internal pressure which was increased from 50 to 200 psig. The major problem experienced and solved during the program was the formation of a plastic liner. The liner also served as the winding mandrel which is the key to keeping the cost competitive with aluminum tanks. The feasibility of the filament wound tank was demonstrated with the successful fabrication of tanks that met all the structural and dimensional requirements. The process practicality was proven; however, the fabrication methods used during this program need to be further refined.

(This document is subject to special controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Filament winding						
Sandwich wall						
Glass reinforced plastic						
Aircraft wing tank						
Structural analysis						

UNCLASSIFIED
Security Classification